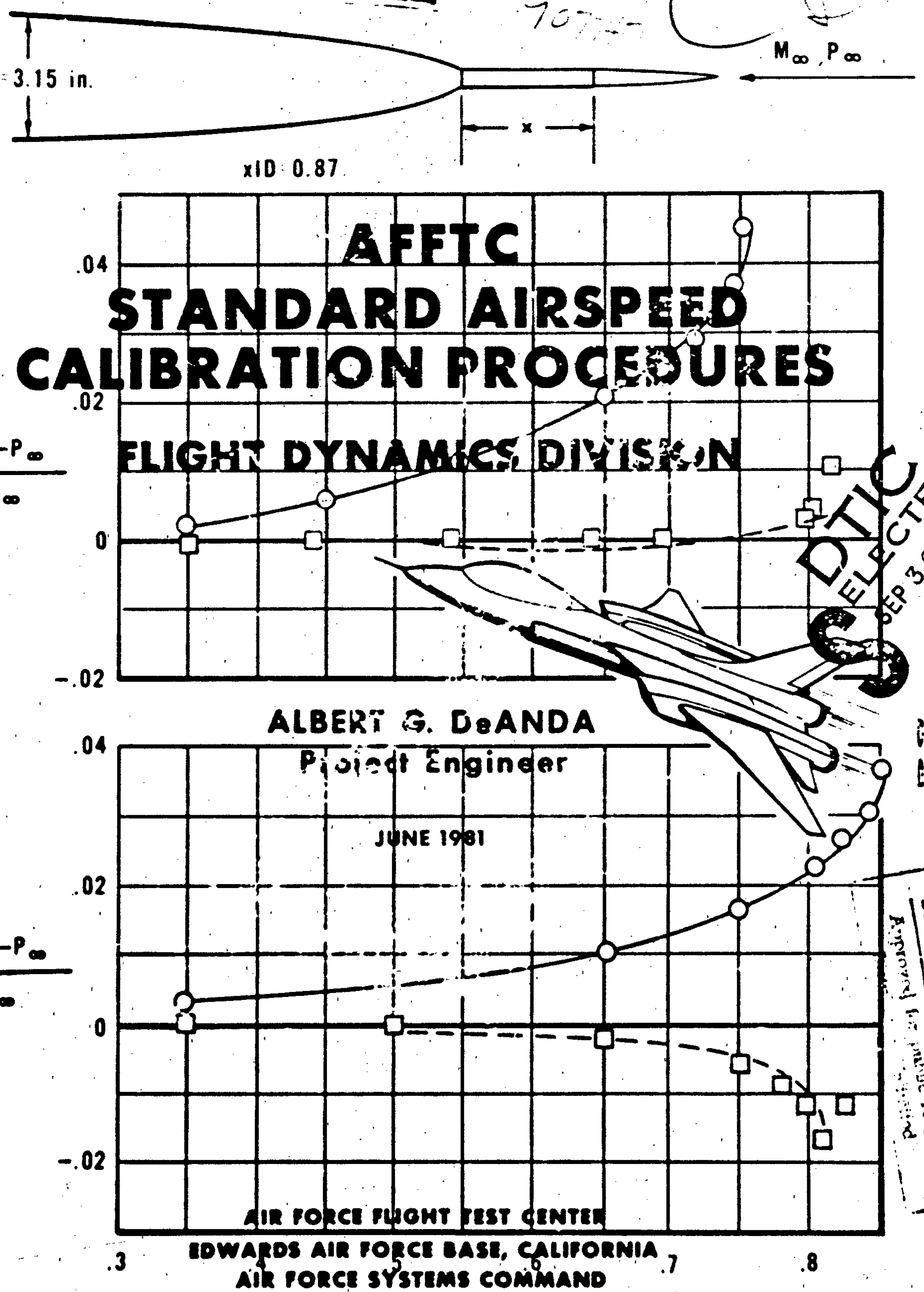
20000728019

LEVEL II

AFFTC-TIH-81-5

AD A104830



AFFTC STANDARD AIRSPEED CALIBRATION PROCEDURES

FLIGHT DYNAMICS DIVISION

ALBERT G. DeANDA
Project Engineer

JUNE 1981

AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

This handbook, AFFTC-TIH-81-5, AFFTC Standard Airspeed Calibration Procedures, was submitted under Job Order Number SC6601 by the Commander, 6520 Test Group, Edwards AFB, California 93523.

This report has been reviewed and cleared for open publication and/or public release by the AFFTC Office of Information in accordance with AFR 190-17 and DODD 5230.9. There is no objection to unlimited distribution of this report to the public at large, or by DDC to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public including foreign nationals.

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EDWARD B. RUSSELL, Colonel, USAF
Commander, 6520 Test Group

UNCLASSIFIED

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Atmospheric Corrections	Pacers	Temperature Probes
Instrument Calibrations	Smoke Trails	
Airspeed Calibrations	Radar Calibrations	
Groundspeed	Lag	
Tower Fly-Bys	End-to-End Checks	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This handbook provides the AFFTC flight test project engineers guidelines and standard procedures in accomplishing airspeed calibrations. The handbook presents suggested airspeed calibrations data reduction methods. Some of the information applies to local AFFTC facilities; however, the data reduction outlines are for general application.

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FOREWORD

This handbook has been compiled as a reference for use by AFFTC flight test engineers in the standard flight test methods, techniques and procedures for airspeed calibrations. Suggested airspeed calibration data reduction methods are presented. Some of the information included in this reference applies to the local AFFTC facilities; however, the data reduction outlines are for general application.

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INTRODUCTION

The position error or airspeed system installation error of any test airplane must be determined by flight test for each test aircraft. This error is the result of the disturbance caused by the airplane as it moves through the air. The magnitude of this error can be reduced by the proper selection of the location for the installation of the pitot-static sensor on the airplane. Figure I 1 is an example of a typical static pressure survey obtained along the fuselage. The fuselage static pressure survey serves to determine the best location on the airplane for the installation of the pitot-static sensor. For flight test purposes, it is desirable to install a pitot-static probe on the end of a long boom attached to the aircraft nose section or wing in order to locate the sensor in a relatively undisturbed static pressure field ahead of the airplane; however, the standard airspeed system is also often used.

To obtain an accurate definition of the airspeed system calibration the test instruments must be carefully calibrated. The instrument calibration laboratory is responsible for providing instrument calibrations. The project engineer is required to provide the limits to which the calibrations are to be conducted, check the results and decide if the instrument is within the required accuracy tolerances.

Altimeter instrument calibrations are usually obtained by using a very accurate laboratory barometer. The altitude scales on these barometers are based on the 1962 U. S. Standard Atmosphere.

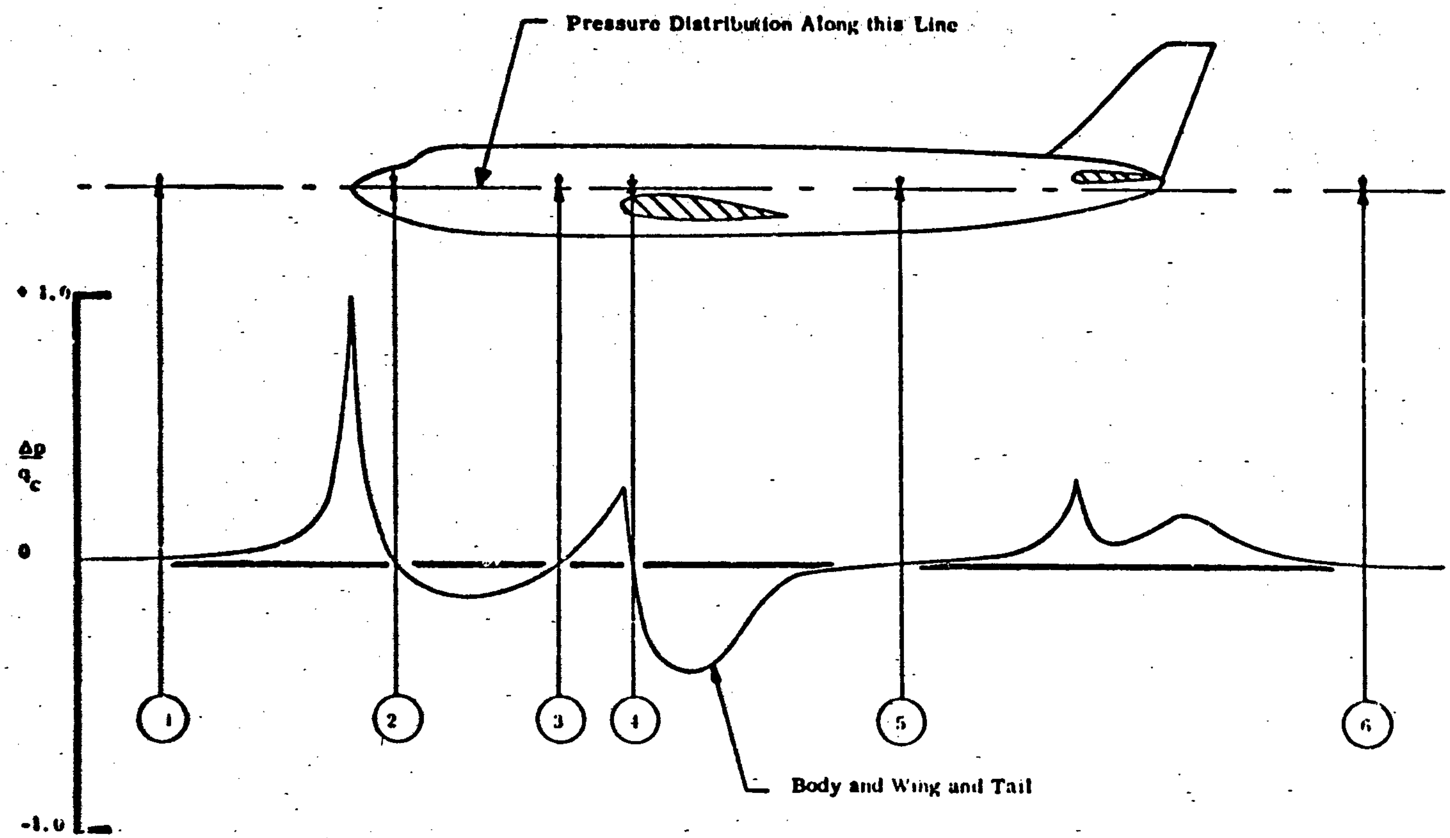


Figure I1 TYPICAL SUCSONIC STATIC PRESSURE DISTRIBUTION ON AIRCRAFT FULELAGE
1 – 6 ARE POINTS OF MINIMUM STATIC PRESSURE ERROR

Before each airspeed calibration flight, the engineer must complete all preflight checks and define the airspeed range and altitude for the flight. The pacer and test aircraft pilots must be thoroughly briefed and have flight cards outlining the flight requirements. A postflight briefing must also be conducted to check the recorded data and note any pilot's comments.

The four methods most commonly used at the AFFTC to determine aircraft pitot-static system position error are:

1. Ground Speed Course Method: This method is used to obtain a pitot-static system calibration by flying the test airplane at a constant speed and altitude approximately 100 to 200 feet above the ground while recording the time required to cover a measured course. This method is mainly used to calibrate relatively slow-flying airplanes with maximum airspeed limits less than 200 knots (such as helicopters).

2. Tower Fly-By Method: This method depends on the altimeter to determine the pitot-static system position error calibration. As the name implies, the test airplane is flown past an observation tower at a constant airspeed and altitude. The tower-fly-by method is considered the most accurate of the various methods used in obtaining airspeed calibrations at low altitude and subsonic airspeeds.

3. Stabilized Pace Method: This method uses a calibrated pacer airplane. The calibration is accomplished by flying both airplanes abreast at a constant altitude and airspeed. This method has the advantage of obtaining a large number of data points in a relatively short time. The accuracy of this method depends directly on the combined accuracies of the pacer and test aircraft instrumentation.

4. Acceleration Method: (Smoke Trail or Radar Tracking) Airspeed calibrations of the pitot-static system are accomplished at altitude in the transonic (0.9 to 1.1 Mach) and for the supersonic airspeed range (above 1.1 Mach) using radar tracking or by use of a smoke trail generated by a pacer aircraft. The method using radar tracking is preferred at the AFFTC. Airspeed calibrations using radar tracking are accomplished by first having a pacer or test airplane conduct a pressure altitude survey of the test altitude region before the accelerations and decelerations are conducted. Correlation of radar tracking data and data recorded by the test airplane instrumentation is accomplished by a sidetone transmitted by the test airplane. A pressure altitude survey is required so that tapeline altitude obtained from radar tracking can be converted to a usable pressure altitude.

The smoke trail acceleration method is also used for the pitot-static system position error calibrations in the transonic and supersonic airspeed range. A pacer airplane generates a smoke trail at a constant airspeed and altitude; the test airplane then accelerates alongside the smoke trail starting at some subsonic airspeed and accelerates well beyond the Mach "jump" and then decelerates. The smoke trail provides a constant altitude reference for the test airplane.

Airspeed calibration results usually reflect the conditions and care taken to obtain the test data. Some factors contributing to the quality of the test results are the weather, pilot technique, and instrument accuracy.

There are a variety of airspeed system installations on the numerous aircraft manufactured and complete familiarization with the airspeed system being calibrated is essential.

For all airspeed calibration methods, the altimeter atmosphere pressure reference must be set at 29.92 inches of mercury.

ATMOSPHERE CORRECTIONS

Altitude indications obtained with altimeters calibrated with labratory barometers which have the scales based on the old NACA Atomosphere (NACA Report No. 538, 1948) can be corrected to the 1962 U.S. Standard Atmosphere.

Altitude indications may be corrected for differences in atmospheres utilizing the following outline:

1. H_i Indicated pressure altitude (NACA 1948 Atomsphere)

2. ΔH_{ic} Instrument correction

3. H_{ic} (1) + (2), indicated altitude corrected for instrument error (NACA 1948 Atomsphere)

4. $P_{a_{ic}}$ Ambient pressure utilizing H_{ic} in one of the following equations:

$$P_{a_{ic}} = 29.92126\ (1-0.00000687535\ H_{ic})^{5.2561}$$

(for $H_{ic} < 36089$ feet)

For altitude at or above 36,089 feet use the following equation:

$$P_{a_{ic}} = 6.92425\ (2.7182818)^{\left(\frac{35332-H_{ic}}{20937.78}\right)}$$

Altitude (U.S. Standard Atmosphere) is obtained using the calculated $P_{a_{ic}}$ in the equation:

$$H_{ic} = \frac{1-\left(\frac{P_{a_{ic}}}{29.92126}\right)^{\frac{1}{5.2559}}}{0.00000687535}$$

$$(\text{for } P_{a_{ic}} \geq 6.68322)$$

For altitude (1962 U. S. Standard Atmosphere) above 36,089 feet, use the calculated $P_{a_{ic}}$ in the following equation:

$$H_{ic} = 4901.7 - \frac{47907.24 \ln\left(\frac{P_{a_{ic}}}{29.9216}\right)}{\ln 10}$$

Altitude data obtained by use of the NACA Atmosphere, 1948, may also be corrected to the U. S. Standard Atmosphere by applying the correction obtained from figure II 1.

Other previously published atmospheres are presented in figure II 2 and a comparison of three standard atmospheres is presented in figure II 3. It must be noted that the standard atmosphere published in the NACA Report No. 1235 closely approximates the presently used 1962 U. S. Standard Atmosphere, up to an altitude of 60,000 feet.

Note:

Correction to be added to the old NACA atmosphere (NACA Report No. 538, 1948) to obtain the correct U.S. Standard Atmosphere (ICAO), NACA Report No. 1235

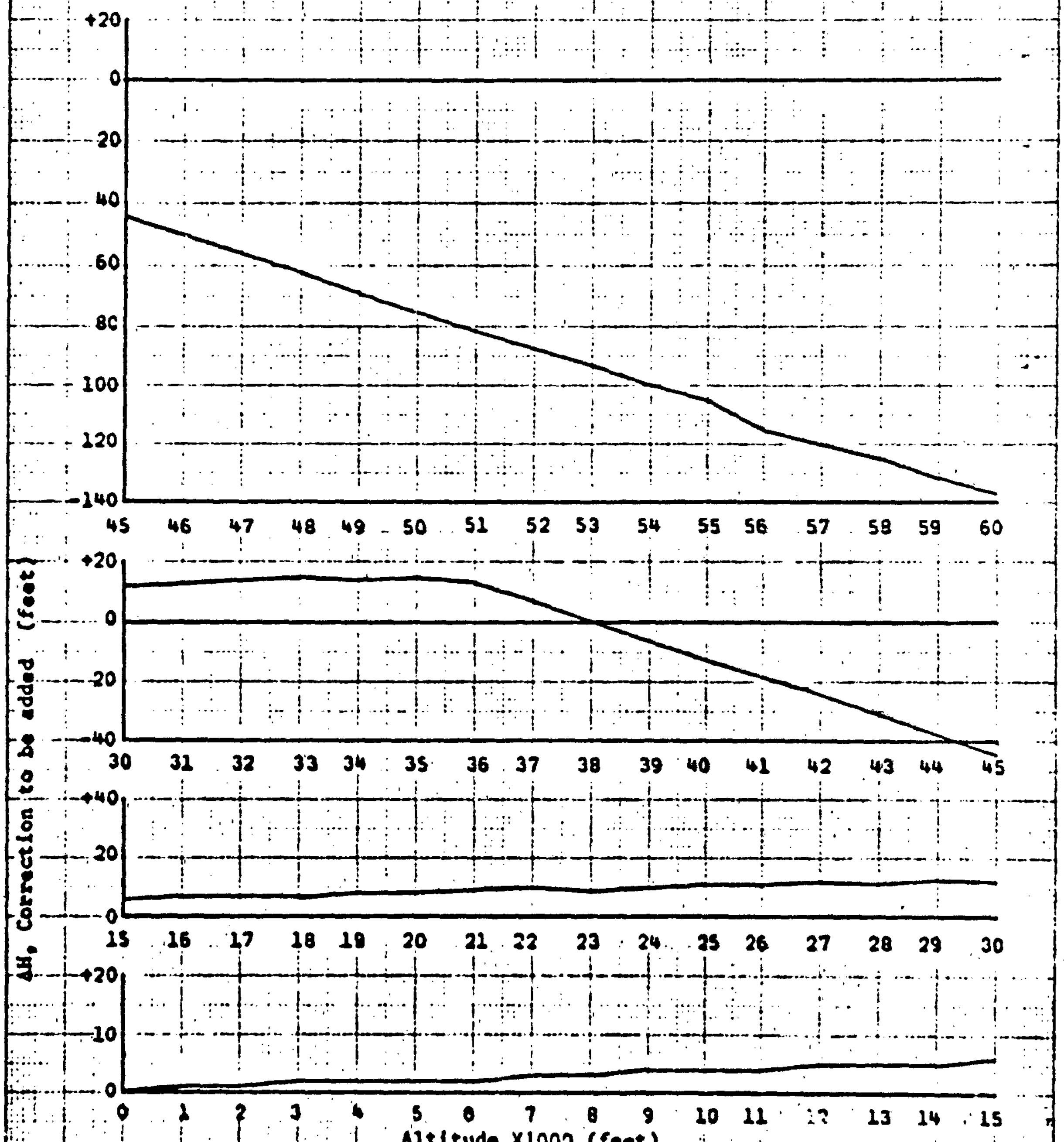


Figure II 1 ALTITUDE CORRECTION

Source: Reference 8

Z = Geometric Feet   H = Geopotential Feet

Pressures Tabulated Are In Units Of Inches Of Mercury Absolute

Z or H	(1) NACA 218 1925 (Z)	(2) NACA 1235 1955 (H)	(3) ARDC 1956 (H)	(4) U.S. STD 1962 (H)
0	29.92	29.9213	29.921	29.9213
5,000	24.89	24.8959	24.896	24.8959
10,000	20.58	20.5769	20.577	20.5770
15,000	16.88	16.8858	16.886	16.8858
20,000	13.75	13.7501	13.750	13.750
25,000	11.10	11.1035	11.103	11.1035
30,000	8.880	8.88541	8.8854	8.88544
35,000	7.036	7.04060	7.0406	7.04062
40,000	5.541	5.53801	5.5380	5.53802
45,000	4.364	4.35497	4.3549	4.35498
50,000	3.436	3.42466	3.4246	3.42466
55,000	2.707	2.69308	2.6931	2.69308
60,000	2.132	2.11778	2.1178	2.11778
65,000	1.680	1.66538		1.66537
70,000			1.3096	1.31046
75,000				1.03290
80,000			.80985	.815462
85,000				.644846
90,000			.50397	.510745
95,000				.405172
100,000			.31951	.321922

Figure II 2 COMPARISON OF VARIOUS STANDARD ATMOSPHERES

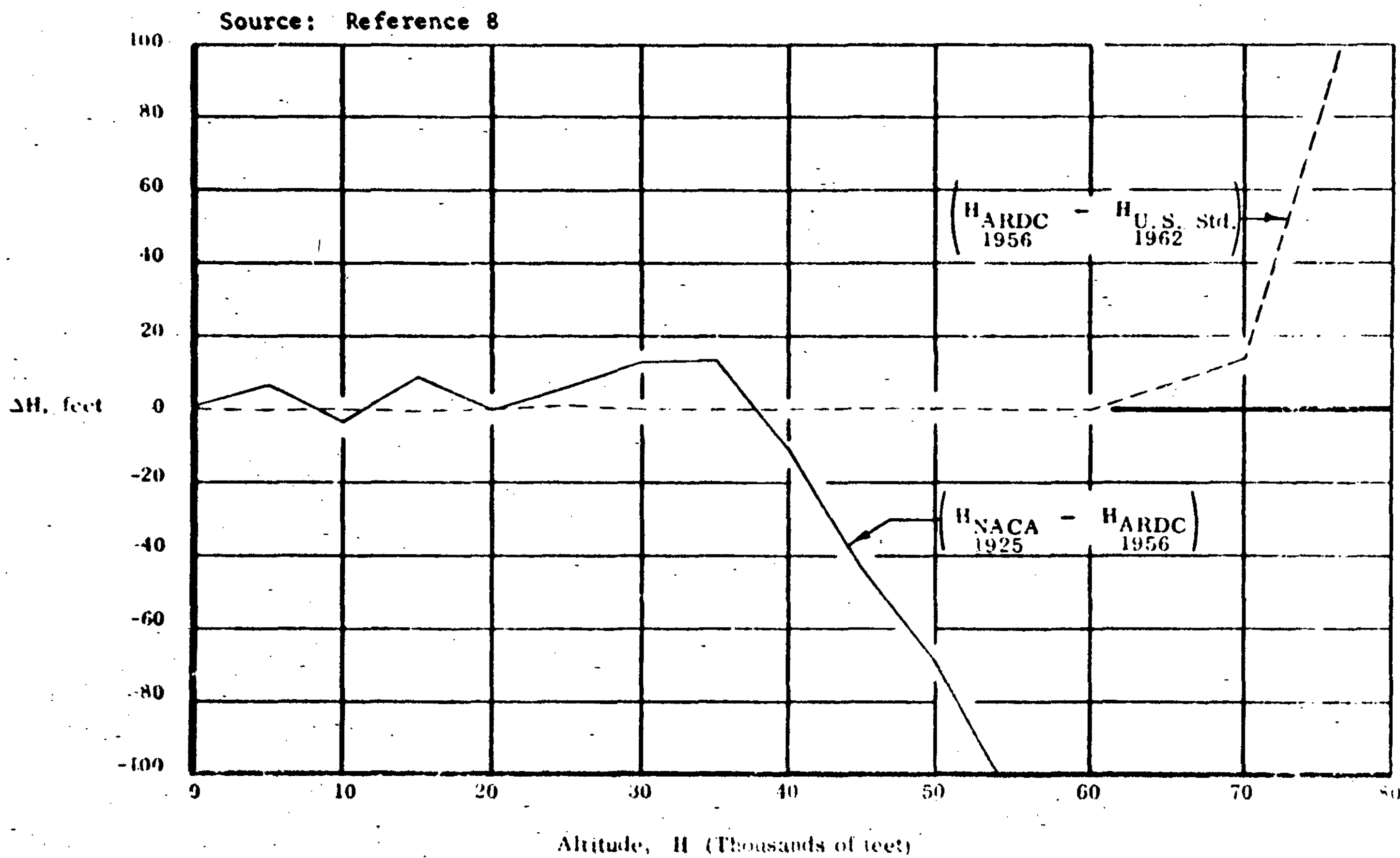


Figure II 3 PRESSURE ALTITUDE DIFFERENCE FOR THREE STANDARD ATMOSPHERES ($\Delta H = \Delta P/\rho$)

INSTRUMENT CALIBRATIONS

The Test and Environmental Evaluation Section (Calibration Laboratory) is responsible for accurately calibrating flight test instruments. The instruments are calibrated in accordance with the specific instructions of the work order request. The requester must clearly specify the range and increments of the calibration.

Airspeed indicators are usually calibrated in increments of 10 knots for both 650- and 850-knot indicators. Other airspeed indicators (for helicopter, zero to 170 knots) are calibrated in other increments, depending on the range specified. The calibrations are usually conducted with increasing readings until the maximum value of the range specified is reached. This portion of the calibration is the "up" calibration. The procedure is reversed by starting with the maximum value reached and using decreasing values until the minimum starting value is again reached. This portion is called the "down" calibration. The difference between the "up" and "down" values at any specific point is the hysteresis value. The quality of the instrument is to some extent determined by the magnitude of the hysteresis. A small hysteresis usually indicates a more accurate instrument. The correction to be applied is the difference between the preset value on the manometer and the value indicated on the instrument. The correction value to be applied is usually the average of the "up" and "down" value.

The altimeter calibration procedure is very similar to the procedure used for airspeed indicator calibrations. An "up" and "down" calibration is normally performed in 1,000-foot increments to 20,000 feet, and 2,000-foot increments to the desired altitude above 20,000 feet.

REDUCTION OF INSTRUMENT CALIBRATION DATA 13 APR 67

INSTRUMENT I.D. NUMBER- 222700113397 DATE OF CALIBRATION 5 APR 1967 WORK ORDER NUMBER- 00478 RUN NO. 2

INSTRUMENTATION ENGINEER- SHARP
REQUESTOR-
OFFICE SYMBOL- FTTSE2
PHONE NUMBER- 73074
LINE ITEM CODE- 330
PARAMETER- NO.-
LOCATION- PACER
REMARKS-

INSTRUMENT I.D. NUMBER- 222700113397
CLASS- ALTIMETER
MFG.- KOLLSMAN
TYPE- UNLISTED
SERIAL NUMBER- 33397
SIGNAL CONDITIONING S/N-
DATA PROCESSING CODE- 10101

WORK ORDER NUMBER- 00478
DATE OF CALIBRATION- 5 APR 1967
CALIBRATED BY- 43
STANDARD USED-
AMBIENT PRESSURE- 27.71 IN HG
AMBIENT TEMPERATURE- 23. DEG C

TABULATED DATA

NO EXTERNAL CONDITIONS

STANDARD READING- (ALTITUDE (FEET) NACA-538

STANDARD READING	INDICATED READING UP	CORRECTION UP	INDICATED READING DOWN	CORRECTION DOWN	HYSTERESIS ERROR	AVERAGE INDICATED READING	AVERAGE CORRECTION
0.	0.25000E 02	-0.25000E 02	0.25000E 02	-0.25000E 02	0.	0.25000E 02	-0.25000E 02
0.10000E 04	0.10251E 04	-0.25000E 02	0.10300E 04	-0.30000E 02	0.50000E 01	0.10275E 04	-0.27500E 02
0.15000E 04	0.15550E 04	-0.35000E 02	0.15500E 04	-0.40000E 02	0.50000E 01	0.15575E 04	-0.37500E 02
0.16000E 04	0.16500E 04	-0.50000E 02	0.16500E 04	-0.50000E 02	0.	0.16500E 04	-0.50000E 02
0.17000E 04	0.17500E 04	-0.50000E 02	0.17500E 04	-0.50000E 02	0.	0.17500E 04	-0.50000E 02
0.18000E 04	0.18500E 04	-0.50000E 02	0.18500E 04	-0.50000E 02	0.	0.18500E 04	-0.50000E 02
0.19000E 04	0.19450E 04	-0.45000E 02	0.19450E 04	-0.45000E 02	0.	0.19450E 04	-0.45000E 02
0.20000E 04	0.20350E 04	-0.35000E 02	0.20350E 04	-0.35000E 02	0.	0.20350E 04	-0.35000E 02
0.21000E 04	0.21200E 04	-0.20000E 02	0.21250E 04	-0.25000E 02	0.50000E 01	0.21225E 04	-0.22500E 02
0.22000E 04	0.22350E 04	-0.35000E 02	0.22350E 04	-0.35000E 02	0.	0.22350E 04	-0.35000E 02
0.23000E 04	0.23400E 04	-0.40000E 02	0.23400E 04	-0.40000E 02	0.	0.23400E 04	-0.40000E 02
0.24000E 04	0.24400E 04	-0.40000E 02	0.24400E 04	-0.40000E 02	0.	0.24400E 04	-0.40000E 02
0.25000E 04	0.25400E 04	-0.40000E 02	0.25450E 04	-0.45000E 02	0.50000E 01	0.25425E 04	-0.42500E 02
0.30000E 04	0.30400E 04	-0.40000E 02	0.30400E 04	-0.40000E 02	0.	0.30400E 04	-0.40000E 02
0.40000E 04	0.40400E 04	-0.40000E 02	0.40450E 04	-0.45000E 02	0.50000E 01	0.40425E 04	-0.42500E 02
0.50000E 04	0.50450E 04	-0.45000E 02	0.50500E 04	-0.50000E 02	0.50000E 01	0.50475E 04	-0.47500E 02
0.60000E [illegible]	0.[illegible]500E 04	-0.50000E 02	0.60550E 04	-0.55[illegible]	[illegible]50000E 01	0.60525E 04	-0.52500E 02
[illegible]000E 05	0.36020E [illegible]	0.80000E 02	0.70550E [illegible]	-0.25000E 02	0.50000E [illegible]	0.70525E 04	-0.52500[illegible]
0.38000E 05	0.38050E 05	-0.500[illegible] 02	[illegible]E 05	-0.50000E 02	0.	0.38[illegible] 04	[illegible]00E 02
0.40000E 05	0.40060E 05	-0.60000E 02	0.40065E 05	-0.65000E 02	0.50000E 01	0.40062E 05	-0.62500E 02
0.42000E 05	0.42050E 05	-0.50000E 02	0.42055E 05	-0.55000E 02	0.50000E 01	0.42052E 05	-0.52500E 02
0.44000E 05	0.44025E 05	-0.25000E 02	0.44025E 05	-0.25000E 02	0.	0.44025E 05	-0.25000E 02
0.46000E 05	0.45985E 05	0.15000E 02	0.45980E 05	0.20000E 02	0.50000E 01	0.45982E 05	0.17500E 02
0.48000E 05	0.47940E 05	0.60000E 02	0.47930E 05	0.70000E 02	0.10000E 02	0.47935E 05	0.65000E 02
0.50000E 05	0.49900E 05	0.10000E 03	0.49900E 05	0.10000E 03	0.	0.49900E 05	0.10000E 03

INSTRUMENT ANALYSIS INFORMATION

AVERAGE CORRECTION	-0.[illegible]1645 02	
AVERAGE HYSTERESIS	0.[illegible]1111E 01	
MAXIMUM POSITIVE CORRECTION	0.10000E 03	STD= 0.50000E 05
MAXIMUM NEGATIVE CORRECTION	-0.65000E 02	STD= 0.40000E 05
MAXIMUM HYSTERESIS	0.20000E 02	STD= 0.22000E 05

Figure III 1 ALTIMETER CALIBRATION

REDUCTION OF INSTRUMENT CALIBRATION DATA [illegible]

INSTRUMENT I.D. NUMBER- 032700105757   DATE OF CALIBRATION 31 MAR 1967   WORK ORDER NUMBER- 00679   RUN NO. 2

INSTRUMENTATION ENGINEER- SHARP
REQUESTOR-
OFFICE SYMBOL- FTTSE2
PHONE NUMBER- 73074
LINE ITEM CODE- 430
PARAMETER- NO.-
LOCATION- PACER
REMARKS-

INSTRUMENT I.D. NUMBER- 032700105757
CLASS- AIR SPEED
MFG.- KOLLSMAN
TYPE- UNLISTED
SERIAL NUMBER- 05757
SIGNAL CONDITIONING S/N-
DATA PROCESSING CODE- 102020

WORK ORDER NUMBER- 00679
DATE OF CALIBRATION- 31 MAR 1967
CALIBRATED BY- HD
STANDARD USED-
AMBIENT PRESSURE- 27.400 IN HG
AMBIENT TEMPERATURE- 25. DEG C.

TABULATED DATA

NO EXTERNAL CONDITIONS

STANDARD READING- (AIRSPEED (KNOTS)

STANDARD READING	INDICATED READING UP	CORRECTION UP	INDICATED READING DOWN	CORRECTION DOWN	HYSTERESIS ERROR	AVERAGE INDICATED READING	AVERAGE CORRECTION
0.80000E 02	0.82000E 02	-0.20000E 01	0.83000E 02	-0.30000E 01	0.10000E 01	0.82500E 02	-0.25000E 01
0.90000E 02	0.91000E 02	-0.10000E 01	0.92000E 02	-0.20000E 01	0.10000E 01	0.91500E 02	-0.15000E 01
0.10000E 03	0.10100E 03	-0.10000E 01	0.10200E 03	-0.20000E 01	0.10000E 01	0.10150E 03	-0.15000E 01
0.11000E 03	0.11100E 03	-0.10000E 01	0.11200E 03	-0.20000E 01	0.10000E 01	0.11150E 03	-0.15000E 01
0.12000E 03	0.12100E 03	-0.10000E 01	0.12200E 03	-0.20000E 01	0.10000E 01	0.12150E 03	-0.15000E 01
0.13000E 03	0.13100E 03	-0.10000E 01	0.13100E 03	-0.10000E 01	0.	0.13100E 03	-0.10000E 01
0.14000E 03	0.14100E 03	-0.10000E 01	0.14100E 03	-0.10000E 01	0.	0.14100E 03	-0.10000E 01
0.15000E 03	0.15000E 03	0.	0.15000E 03	0.	0.	0.15000E 03	0.
0.16000E 03	0.16000E 03	0.	0.16000E 03	0.	0.	0.16000E 03	0.
0.17000E 03	0.17000E 03	0.	0.17000E 03	0.	0.	0.17000E 03	0.
0.18000E 03	0.18000E 03	0.	0.18000E 03	0.	0.	0.18000E 03	0.
0.19000E 03	0.19000E 03	0.	0.19000E 03	0.	0.	0.19000E 03	0.
0.20000E 03	0.20000E 03	0.	0.20100E 03	-0.10000E 01	0.10000E 01	0.20050E 03	-0.50000E 00
0.21000E 03	0.21100E 03	-0.10000E 01	0.21200E 03	-0.20000E 01	0.10000E 01	0.21150E 03	-0.15000E 01
0.22000E 03	0.22100E 03	-0.10000E 01	0.22100E 03	-0.10000E 01	0.	0.22100E 03	-0.10000E 01
0.23000E 03	0.23000E 03	0.	0.23100E 03	-0.10000E 01	0.10000E 01	0.23050E 03	-0.50000E 00
0.24000E 03	0.24000E 03	0.	0.24000E 03	0.	0.	0.24000E 03	0.
0.25000E 03	0.25000E 03	0.	0.25000E 03	0.	0.	0.25000E 03	0.
0.2[illegible]	[illegible] 03	0.	0.26000E 03	[illegible]	[illegible]	0.26000E 03	0.
[illegible]5000E 03	0.55000E [illegible]	[illegible]	0.27[illegible]	0.	0.	[illegible]	0.
0.60000E 03	0.60000E 03	0.	[illegible]00E 03	0.	0.	0.60000E 03	0.
0.65000E 03	0.65000E 03	0.	0.65000E 03	0.	0.	0.65000E 03	0.
0.70000E 03	0.70000E 03	0.	0.70000E 03	0.	0.	0.70000E 03	0.
0.75000E 03	0.75000E 03	0.	0.75000E 03	0.	0.	0.75000E 03	0.
0.80000E 03	0.80000E 03	0.	0.80000E 03	0.	0.	0.80000E 03	0.
0.85000E 03	0.85000E 03	0.	0.85000E 03	0.	0.	0.85000E 03	0.

INSTRUMENT ANALYSIS INFORMATION

AVERAGE CORRECTION	-0.38554E-00	
AVERAGE HYSTERESIS	0.34145E-00	
MAXIMUM POSITIVE CORRECTION	0.10000E 01	STD= 0.28000E 03
MAXIMUM NEGATIVE CORRECTION	-0.30000E 01	STD= 0.80000E 02
MAXIMUM HYSTERESIS	0.20000E 01	STD= 0.40000E 03

Figure III 2 AIRSPEED INDICATOR CALIBRATION

Airspeed indicator and altimeter instrument calibrations must be carefully checked because of the importance of these parameters in determining overall aircraft performance. Figures III 1 and III 2 are typical laboratory calibrations for an altimeter and an airspeed indicator, respectively.

Altimeters are designed to compensate for variations in ambient temperature conditions; however, laboratory calibrations have shown that not all altimeters adequately compensate for changes in environmental temperature. Environmental calibrations for various altimeters have shown the normal calibrations to change as much as 50 to 75 feet (at 40,000 feet) for a change of approximately 10 degrees C. Other altimeter calibrations have shown negligible temperature effects. The effects of environmental temperature change on altimeters is unpredictable and altimeters should be checked for temperature effects if the instrument is to be used in a temperature environment that differs markedly from that of the calibration laboratory.

AIRSPEED CALIBRATION METHODS

Several methods are used to obtain airspeed calibrations. The groundspeed course, tower fly-bys, stabilized paces, and smoke trail accelerations are the four most common methods of obtaining the position error curve. Other methods for calibrating pitot-static airspeed systems use the trailing bomb, trailing cone, and radar or Askania tracking.

The trailing bomb method uses a bomb with a static pressure sensor which trails below and slightly behind the aircraft. The trailing bomb installation is primarily used to measure the pressure altitude of the airplane by a pressure sensor outside the disturbed flow field of the test aircraft. The static pressure is transmitted to instrumentation aboard the airplane through tubing. Instability of the bomb at high and low airspeeds and high lag are its main disadvantages.

The trailing cone is a fairly recent development. The function of this system is the same as that of the trailing bomb. This system is designed to directly measure the pressure altitude (same as the trailing bomb) since the disturbed flow around the aircraft returns to ambient pressure at some distance behind the airplane. Airspeed calibrations to higher airspeeds can be accomplished with this system since the cone is stable at the higher airspeeds.

Askania (phototheodolite) or radar tracking is used to calibrate airspeed system installations at high altitudes and high speeds. This method provides a tapeline altitude which is converted to pressure altitude for use in determining the position error. A pressure survey must be accomplished in the test altitude region where the calibration is to be conducted. The pressure survey is performed with a calibrated pacer aircraft or weather balloon.

Following are descriptions and suggested procedures for conducting calibrations by the four most commonly used airspeed calibration methods:

1. Groundspeed Course:

The groundspeed course method is most commonly used in calibrating airspeed system of relatively slow airplanes (less than 200 knots) and is extensively used to calibrate helicopter airspeed systems. The objective of this test is to obtain true airspeed from time and ground distance measurements. The test airplane is flown over a measured course at a constant speed from 100 to 200 feet above the ground. Each pass is repeated in the opposite direction to average the groundspeed and effectively cancel wind effects. Height above the ground should be at least one wing spean to preclude errors from ground effect. Calibrated airspeed is obtained from the resulting true airspeed, ambient temperature, and pressure altitude. The airspeed position error (ΔV_{pc}) is calculated. From this error the static pressure error (ΔH_{pc}) may be determined. In this test, as in all airspeed calibration tests, the total head error is assumed to be zero or negligible. On some very slow aircraft, such as the helicopters, swivel pitot-static heads may be installed to reduce the possibility of introducing a total head error due to high angles of attack or sideslip.

The accuracy of this test is a direct function of the timing accuracy, with accurate timing becoming more critical at the higher speeds. The best time to conduct this test is early in the morning when calm wind and nonturbulent conditions usually prevail. Other factors contributing to the accuracy of data are the errors due to instrument readability and altitude estimation for determining ambient temperatures required for calculation of calibrated speed. Figure IV 1 and IV 2 show the location of the

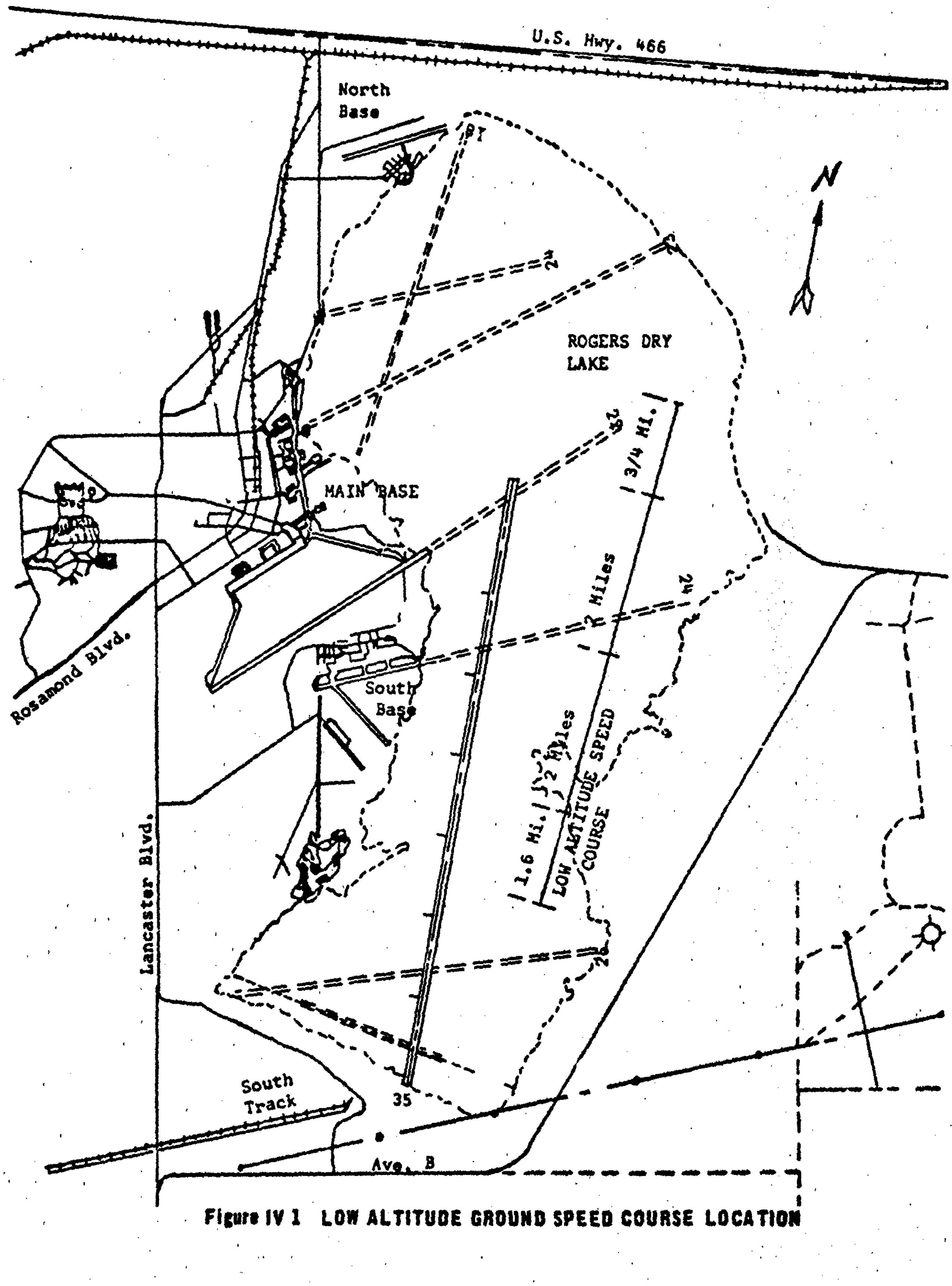
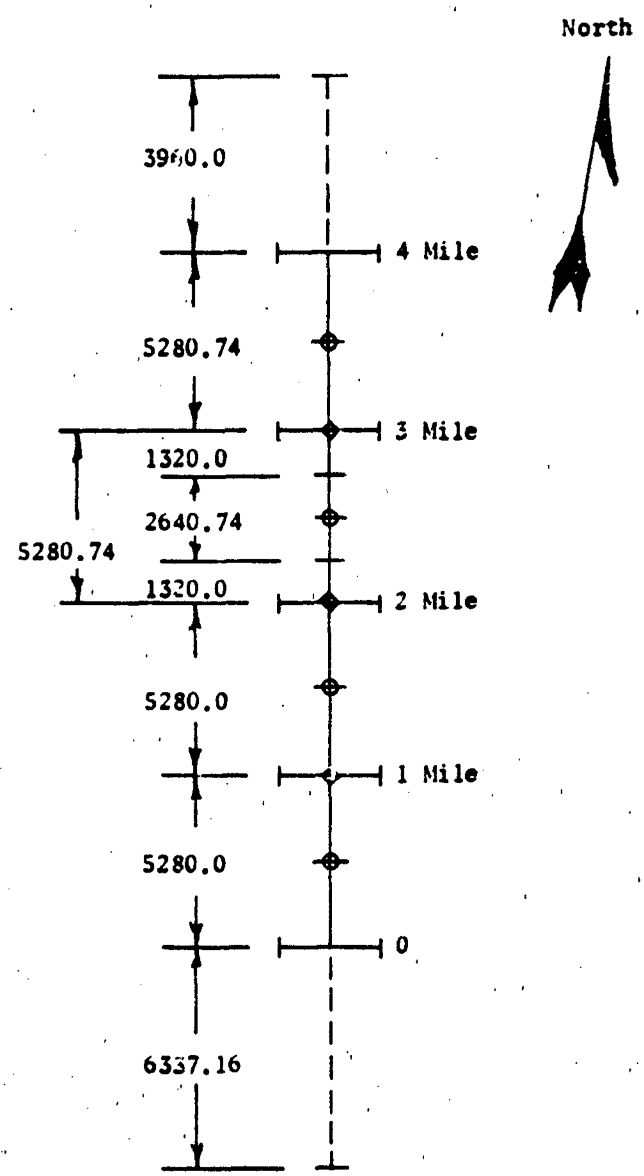
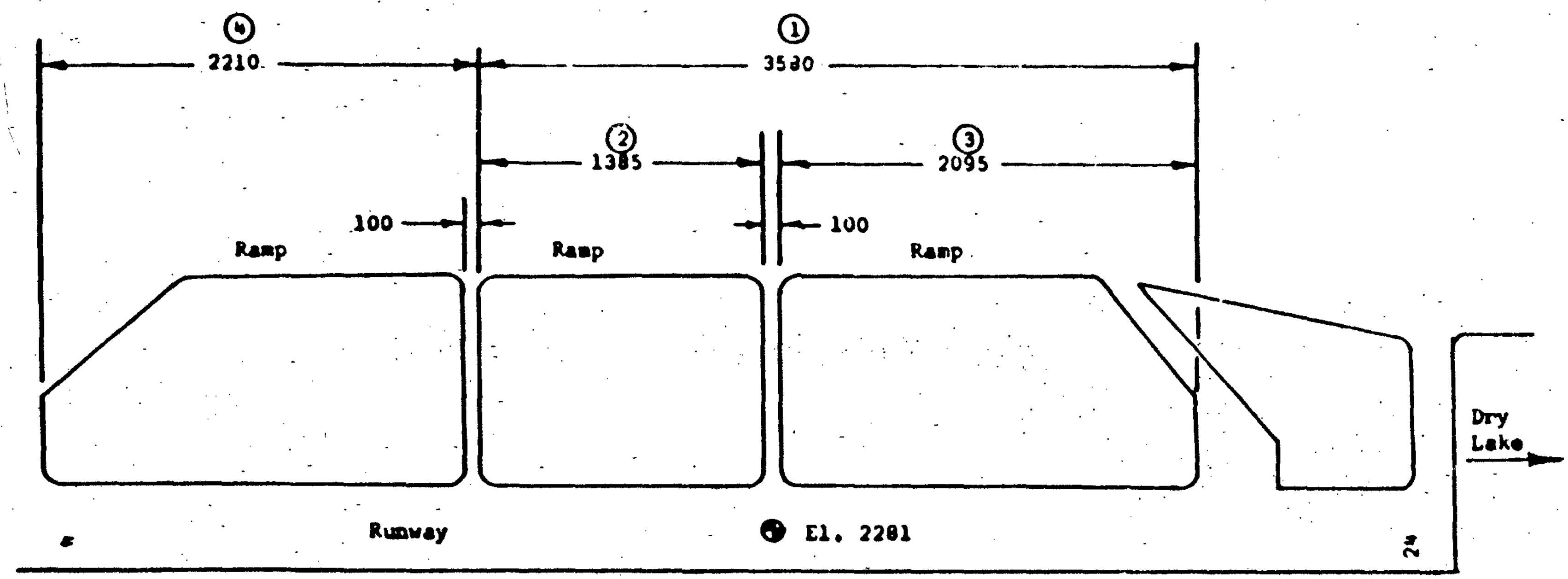


Figure IV 1 LOW ALTITUDE GROUND SPEED COURSE LOCATION



Note:
All Dimensions are in Feet.

Figure IV 2 LOW ALTITUDE GROUND SPEED COURSE DIMENSIONS



Note

1. All dimension are in feet.
2. Course numbers are circled.

Figure IV 3 SOUTH BASE GROUND SPEED COURSE

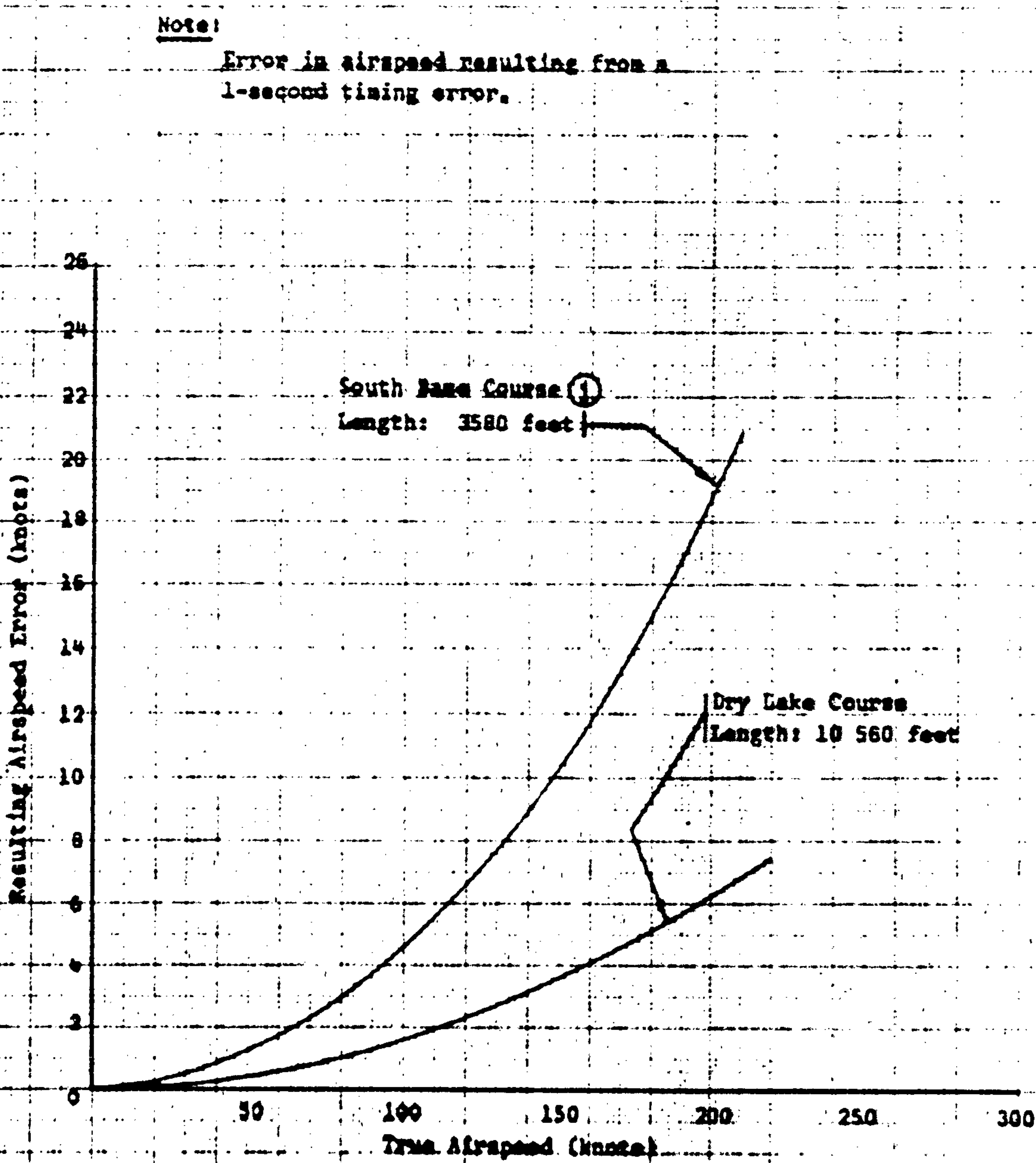


Figure IV 4 Ground Speed Course Time-Airspeed Error

DATE:__________ FLT NO. ________ AIRPLANE:__________ SER. NO.:__________

PILOT:__________________ ALTIMETER SER. NO.:________ SETTING: 29.92"Hg.

OBSERVER:__________________ AIRSPEED IND. SER. NO.:__________________

Pass No.	Ctr. No.	Dir.	Time of Day	Course	Aim Speed V_i	Actual Speed V_i	Altitude H_i	Time ΔT sec.	FAT Deg C	Configuration
1										
1R										
2										
2R										
3										
3R										
4										
4R										
5										
5R										
6										
6R										
7										
7R										
8										
8R										
9										
9R										
10										
10R										

Figure IV 5 GROUND SPEED COURSE DATA

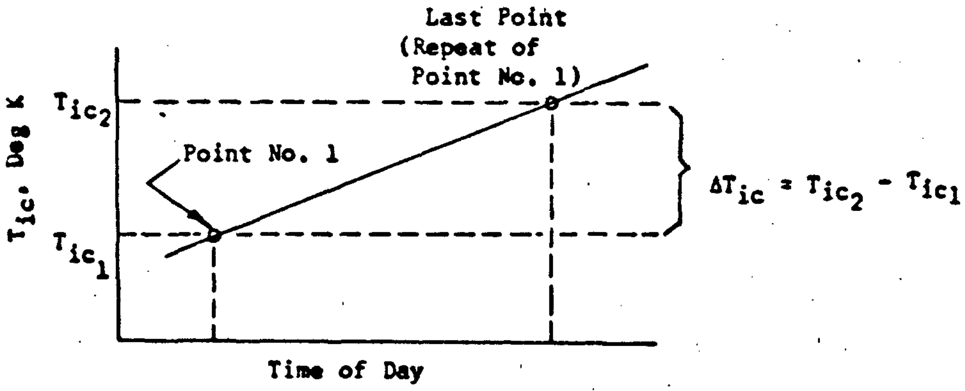


Figure IV 6

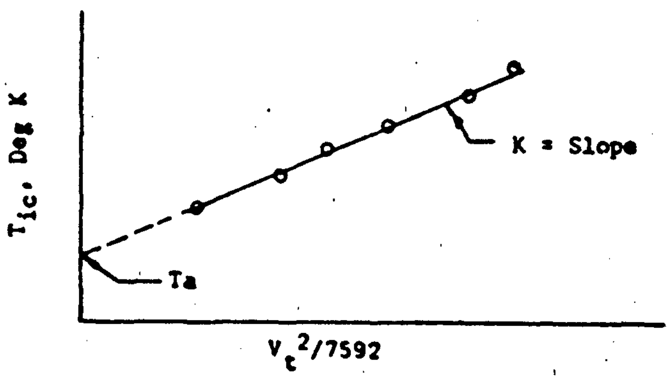


Figure IV 7

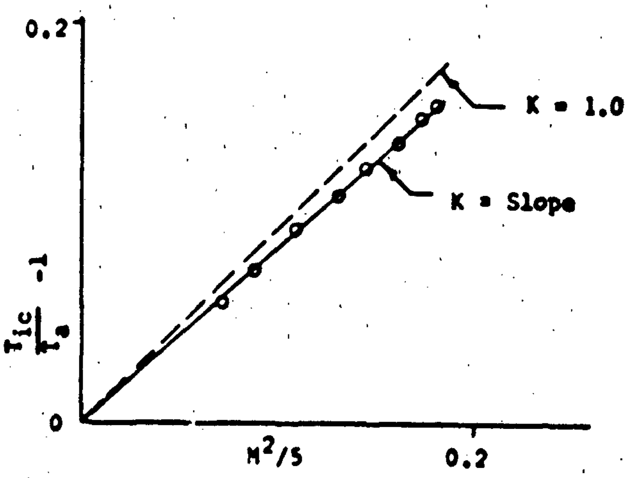


Figure IV 8

GROUND SPEED COURSE TEMPERATURE PROBE DATA

AFFTC low altitude speed course on Rogers Dry Lake. Figure IV 3 depicts the South Base course usually used by helicopters. Figure IV 4 illustrates the error in true airspeed resulting from a 1-second timing error for both speed courses.

The following checklists are presented for planning and performing a pitot-static system calibration by the groundspeed course mehtod:

Engineer's Checklist.

Schedule test airplane as prescribed in latest revision of AFFTC Regulation 55-15.

Preflight

1. Check on maintenance status of airplane.

2. Notify the maintenance control section of the schedule and if required, request an instrumentation preflight and postflight check, and request a preflight continuity and leak check of the airspeed system.

3. Obtain an accurate stopwatch. (It is a good practice to have a second stopwatch as a backup.)

4. Prepare a flight card and select the airspeed points to be flown (see figure IV 5).

5. Brief pilot on all details of proposed calibration flight.

6. Brief flight observer, if an observer is to record data, when the pilot is briefed.

7. Request ambient temperature and pressure be recorded periodically by ground personnel or the weather organization during the test.

Flight Phase

1. Set altimeter(s) at 29.92 in. Hg.

2. Operate any instrumentation required to record test data.

3. Record test data on a form as shown in figure IV 5.

4. Provide event marks for data identification.

5. Record any significant remarks or observations.

Postflight

1. Hold postflight briefing.

2. Obtain data card from pilot or observer.

3. Check all recorded data carefully.

4. Request an instrumentation postflight check if required.

5. Obtain weather recordings.

Pilot's Checklist.

Pref?ight

1. Check status of airplane.

2. Hold briefing with project engineer.

3. Obtain flight test data cards.

Flight Phase (if no observer is utilized)

Use same checklist as used by the project engineer.

.stflight

1. Hold postflight briefing with project engineer.

2. Review all recorded calibration data with project engineer.

3. Provide any remarks or observation required for explanation of recorded data.

Flight Observer's Checklist.

Preflight

1. Attend briefing with pilot and project engineer.

2. Obtain data card.

3. Obtain stopwatch.

4. Obtain detailed instructions required for operation of instrumentation.

Flight Phase

Use same flight phase checklist used by the project engineer.

Postflight

Same as postflight phase checklist as used by pilot.

Data Reduction Outline.

The following is a data reduction outline for a groundspeed course calibration:

Step	Parameter	Unit	Description
1	Point No.	----	Sequence
2	Direction	----	General heading
3	Counter No.	----	Correlation
4	Time	hr and min	Time of day
5	Course Length	feet	Length of course used
6	t_1	sec	Time of initial pass
7	t_2	sec	Time of pass in the reciprocal direction
8	V_{g_1}	ft per sec	5/6, Ground speed initial pass
9	V_{g_2}	ft per sec	5/7, Ground speed of reciprocal pass
10	$V_{g_{avg}}$	ft per sec	(8+9)/2, Average ground speed
11	V_{tt}	knots	10 x 0.5921
12	V_{i_1}	knots	Indicated airspeed, initial pass
13	V_{i_2}	knots	Indicated airspeed, reciprocal pass
14	ΔV_{ic_1}	knots	Airspeed indicator instrument correction, initial pass
15	ΔV_{ic_2}	knots	Airspeed indicator instrument correction, reciprocal pass
16	V_{ic_1}	knots	12 + 14, Airspeed corrected for instrument error
17	V_{ic_2}	knots	13 + 15, Airspeed corrected for instrument error

Step	Parameter	Unit	Description
18	$V_{ic\ avg}$	knots	(16 + 17)/ 2, Average indicated airspeed
19	H_{i_1}	feet	Indicated altitude, initial pass
20	H_{i_2}	feet	Indicated altitude, reciprocal pass
21	ΔH_{ic_1}	feet	Altimeter Instrument correction, initial pass
22	ΔH_{ic_2}	feet	Altimeter instrument correction, reciprocal pass
23	H_{ic_1}	feet	21 + 24, Indicated altitude corrected for instrument error, initial pass
24	H_{ic_2}	feet	22 + 24, Indicated altitude corrected for instrument error, reciprocal pass
25	$H_{ic\ avg}$	feet	(23 + 24)/ 2, Average indicated altitude
26	t_{i_1}	deg C	Indicated temperature, initial pass
27	t_{i_2}	deg C	Indicated temperature, reciprocal pass
28	Δt_{i_1}	deg C	Temperature corrected for instrument error
29	Δt_{i_2}	deg C	Temperature corrected for instrument error
30	t_{ic_1}	deg C	26 + 28 , Indicated temperature corrected for instrument error
31	t_{ic_2}	deg C	27 + 29, Indicated temperature corrected for instrument error
32	$t_{ic\ avg}$	deg C	(30 + 31)/ 2, Average indicated temperature
33	$T_{ic\ avg}$	deg K	32 + 273.16, Average temperature

Step	Parameter	Unit	Description
34	t_{a_t}	deg C	Test ambient temperature (recorded by ground personnel, weather station or by airplane instrumentation)
35	T_{a_t}	deg K	Test ambient temperature, 34 + 273.16
36	P_a	in. Hg	Ambient pressure (recorded by ground personnel, airplane altimeter or weather station)
37	ΔH	feet	Estimated height above ground
38	ΔP_a	in. Hg	(37 x 0.001)
39	$P_{a_{a/c}}$	in. Hg	36 - 38
40	$t_{a_{wb}}$	deg F	Wet bulb ambient temperature, recorded by ground personnel or weather station
41	$t_{a_{db}}$	deg F	Dry Bulb ambient temperature recorded at same time as step 40

NOTE: Determine if a humidity correction is required by using figure V 13 and steps 40 and 41 . If no humidity correction is required, omit data reduction steps 48 through 55 ; however, if a correction is required, then omit steps 42 through 47 . (An 80 percent relative humidity condition results in approximately 1.0 knot error for each 100 knots of airspeed if the humidity correction is neglected.)

42	σ_t	----	9.6306 39 / 35
43	$\sqrt{\sigma_t}$	----	$\sqrt{42}$
44	V_e	knots	11 x 43, Equivalent airspeed, $V_{t_t} \cdot \sqrt{\sigma_t}$
45	ΔV_c	knots	Compressibility correction, small at low altitude and airspeed less than 200 knots, figure V 5 in the Appendix
46	V_c	knots	44 + 45, Calibrated airspeed, $V_e + \Delta V_c$

Step	Parameter	Unit	Description
47	ΔV_{pc}	knots	46 - 18, Airspeed position error correction
48	e	in. Hg	Figure V 13 and steps 40 and 41
49	$P_{a_{a/c\ Corr}}$	in. Hg	39 - (0.374 48), Airplane ambient pressure corrected for vapor pressure
50	σ_t	----	9.6306 49 / 35
51	$\sqrt{\sigma_t}$	----	$\sqrt{50}$
52	V_e	knots	11 x 51 , Equivalent airspeed, $V_{t_t} \sqrt{\sigma_t}$
53	ΔV_c	knots	Compressibility correction, small at low altitude and airspeed less than 200 knots, figure V 13 in the Appendix
54	V_c	knots	52 + 53 , Calibration airspeed, $V_c = V_e + \Delta V_c$
55	ΔV_{pc}	knots	54 - 18 , Airspeed position error correction

The following is a reduction outline to determine the test temperature probe recovery factor:

Step	Parameter	Unit	Description
56	$V_{t_t}{}^2$	$(\text{knots})^2$	$(11)^2$
57	$V_{t_t}{}^2/7592$	----	56 /7592
58	$T_{ic_{Corr}}$	deg K	33 + ΔT_{ic}, indicated temperature (FAT) corrected (from figure IV 6)
59	K_t	----	Temperature probe recovery factor from the slope of $T_{ic_{Corr}}$ vs $V_{t_t}{}^2/7592$, 58 vs 47
60	M_{ic}	----	From 18 and 25 , Indicated Mach number
61	$\Delta M_{pc}/\Delta V_{pc}$	1/knot	25 and 60 figure V 6 in the Appendix
62	ΔM_{pc}	----	47 or 55 x 61, Position error correction

Step	Parameter	Unit	Description
63	M	----	60 + 62 Calibrated Mach number
64	M^2	----	$(63)^2$
65	$M^2/5$	----	64 /5
66	T_{ic}/T_a	----	33 / 35
67	$(T_{ic}/T_a - 1)$	----	(66 - 1)
68	K	----	Slope of plot 67 vs 65 Figure IV 8
69	$\Delta P_p/q_{c_{ic}}$	----	Position error pressure coefficient, 47 or 55 and 18 , and figure V 7 in the Appendix
70	$\Delta H_{pc}/\Delta V_{pc}$	feet per knot	18 and 25 , and figure V 8 in the Appendix
71	ΔH_{pc}	feet	47 or 55 x 70 Position correction
72	S	sq ft	Wing area
73	W_t	lb	Gross weight
74	C_L	----	Lift coefficient = $\frac{295 \times 73}{42 \times 56 \times 72}$ or $\frac{295 \times 73}{50 \times 56 \times 72}$

Results of groundspeed course calibration are normally presented in the following plots:

1. ΔV_{pc} vs V_{ic}
2. ΔH_{pc} vs V_{ic}
3. ΔM_{pc} vs M_{ic}
4. $\Delta P/qc_{ic}$ vs M_{ic}
5. $\Delta P/qc_{ic}$ vs C_L

Plots for temperature probe recovery factor:

1. $V_{t_t}{}^2/7592$ vs T_{ic}
2. $(T_{ic}/T_a - 1)$ vs $M^2/5$

General Remarks.

The temperature probe calibration is conducted on the assumption that the ambient temperature does not change; however, since the temperature will usually change, it becomes necessary to make a check by reflying the first point under conditions similar to the first pass and recording the indicated temperature (t_i). A prorate plot is then made by plotting the indicated temperature (T_{ic}) recorded for the first and the repeated pass against time of day (figure IV 6). Differences in the two indicated temperatures can be attributed to the change in ambient temperature. This plot is then used to correct the indicated temperature recorded during the test period.

Figure IV 7 and IV 8 are plots usually used to obtain temperature probe recovery factors.

2. Tower Fly-Byethod:

The tower fly-by method is considered the most accurate of the commonly used methods for obtaining an airspeed (static source) position error calibration. With this method, the altimeter is used to directly measure the static pressure source error.

Tower fly-by data are usually reduced by one of two methods. The objective of both methods is to obtain the pressure altitude of the test airplane when flown past an observation tower.

Barometric Pressure Source.

This method derives the test airplane ambient pressure in inches of mercury by using the barometric pressure readings (P_a). A very accurate pressure transducer, such as a Kollsman Pressure Monitor (PPM), can be used to obtain ambient pressure. The pressure at the test altitude is then obtained by subtracting

the incremental pressure corresponding to the incremental height (ΔH_t) observed at the fly-by tower. The resulting test pressure at the test altitude, ($P_{a_{a/c}}$) obtained in inches of mercury, is then converted to the equivalent pressure altitude ($H_{c_{a/c}}$) in units of feet. the observed incremental height (ΔH_t) is converted to incremental pressure by the approximate relation, 0.001 inches of mercury equals 1 foot of altitude, (.001 in. Hg ≈ 1 foot).

The following equations are used to derive the test pressure altitude:

$$P_{a_{a/c}} = P_a - (0.001 \times \Delta H_t)$$

or $$H_{c_{a/c}} = H_c + \Delta H_t$$

$$\Delta H_{pc} = H_{c_{a/c}} - H_{ic}$$

The position error (ΔH_{pc}) is the difference between pressure altitude and the indicated altitude observed at the instant the airplane passes the observation tower.

Ground Block Method.

The preferred method for tower fly-by data reduction at the AFFTC is the "ground block method". This method usually gives more accurate data than the barometric pressure method. All tower fly-by data for the AFFTC pacer aircraft are reduced by this method.

The advantage of the ground block method is that the calibration results depend on incremental readings of the altimeter(s) installed in the test aircraft and no other pressure references are introduced. It is important that the altimeter(s) be carefully

calibrated, checked for stickiness or sluggishness and mounted in a panel where a vibrator is provided. Tapping or vibrating the altimeter will relieve the internal friction and decrease the hysteresis of the instrument.

With the ground block method, pressure altitude (H_C) is obtained by adding the height of the test airplane, obtained from the fly-by tower observation, to the test aircraft altimeter reading recorded prior to takeoff. Several ground block readings of the test aircraft altimeters are required at various locations and the corresponding time of day, before and after the flight, for a complete tower fly-by calibration. These altimeter ground block readings are normally recorded prior to takeoff, and a short time after the test aircraft has landed. One or several altimeters may also be read at the location of the test aircraft prior to takeoff and after landing. These altimeters are also taken to the observation tower and read and recorded for each pass. These extra altimeter readings are used as an aid in interpreting ground block barometric pressure trends.

Tower fly-bys are normally conducted early in the morning because of weather and air traffic considerations.

Fly-By Tower Facility.

The AFFTC fly-by tower is located northwest of the approach end to runway 22 about 500 feet from the west shore of the dry lake. (See figure IV 22.) The tower is located on the dry lake to take advantage of the smooth air-conditions which normally prevails over the dry lake during the early morning hours. Figures IV 18 to IV 21 show the tower installation and details. A map of the main base, figure IV 22, indicates the location and route to the tower.

Electrical power for the tower is supplied by an electric powerplant driven by an internal combustion engine. The powerplant is housed in an all-metal shelter at the base of the tower. The power unit is started by placing the start-stop switch, which is located on the instrument panel as shown in figure IV 21, to the "start" position. Once the engine is running, the switch is returned to the "run" position. Electrical power supplied to the tower is 115 vac/60 cycles, 220 vac for the heater and 28 vdc for instrumentation is provided by a rectifier unit installed in the observation cab. The power unit is stopped by moving the switch to the "stop" position and held there until the engine stops. Extensive cranking of the engine may be required when attempting to start the powerplant during cold weather. Usually about 10 seconds of continuous cranking will be required to pump fuel to the carburetor. Choking is not required since this function is automatic. The shelter doors must be left open during operation to provide proper ventilation for engine cooling. The powerplant must be started before going upstairs to the tower observation cab in order to avoid the inconvenience of having to descend to start the unit.

The powerplant is checked and serviced periodically by Civil Engineering (Work Control Office: extension 3330).

A radio unit is provided for communication with the test aircraft or the main control tower. Channel 1 (tower frequency, 236.6 mc) is normally used when conducting tower fly-by tests. This is necessary since the test aircraft is required to report to the control tower after turning on the approach leg of each fly-by pass. Conversations on Channel 1 (tower frequency) must be kept to a minimum in order not to interfere with communications between the tower and other aircraft in the vicinity. The radio call for the fly-by tower is "Edwards Fly-By".

A telephone is also provided in the tower and the extension number is 3659. Communications with Edwards control tower can be obtained by calling telephone extension 4620 or 3420 if the fly-by tower radio becomes inoperative and communication with the test aircraft is required.

Figure IV 11 is the calibration of the fly-by tower theodolite. Information regarding distances and elevations is provided on the calibration plot. Additional information is also presented in figure IV 13 for the various elevations required for calculation of tower fly-by data obtained from either the tower on the lake or the east Askania tower (stand-by facility). These elevations may be required for reduction of tower fly-by data by the ground block method. The theodolite calibration is for use with data obtained with either the cameras or the peep sight.

Tower fly-by data are obtained by hand recorded observations through the peep sight. Data can also be recorded on film by a Polaroid camera. The camera data are considered to be supplemental information and should <u>not</u> be obtained in lieu of peep sight readings. The Polaroid camera film will have to be obtained from Base Supply. Operating instructions for the Polaroid camera are provided in the Appendix. A 4 x 5 inch picture is obtained, which, if photographed at the right time, will contain an image of the airplane behind the grid. (See example, figure IV 17.) A series of alligator clamps are installed along the upper edge of the east window to hold the processed pictures as the test airplane is photographed on each fly-by pass.

A free air temperature indicating system is also installed in the observation cab. The temperature system utilizes a Rosemount probe (Model 102AL) and a Howell indicator. Electrical power for the system is provided by an electrical power rectifier unit. The rectifier is started by operating a small lever on the upper right

corner on the front of the unit. The lever is moved to the right and held firmly for approximately 5 to 10 seconds. The lever will remain in that position during the time the free air temperature system is in use. To turn "off" the power, the lever is moved to the left. Other switches on the rectifier unit must not be touched.

All proposed tower fly-by missions are scheduled through the Center Scheduling Office and must be submitted on the weekly schedule, Form 16. Each project engineer is responsible for specifying the amount of Polaroid film required for the tower fly-by airspeed calibration tests. The Polaroid film requirements will be determined during the planning stages of the test program and included in the Test Support Plan requirements. Use of the Polaroid camera is optional.

The tower key can be obtained from the Building Custodian.

Any organization using the fly-by tower facility is requested to do the following after using the tower:

1. Lock all doors.

2. Shut the electric power unit off.

3. Return the Polariod camera.

4. Return tower key.

5. Report any discrepancies to the Building Custodian.

Figure IV 12 is the tower fly-by theodolite calibration for the east Askania tower (stand-by fly-by) installation. Note that this theodolite calibration is referenced to the base weather

station. This is done so the tower fly-by calibrations may be easily accomplished using the weather station barometric pressure readings as described earlier.

Figure IV 13 is a sketch of various elevations at the AFFTC flight line which may be required for reducing tower fly-by data by the ground block method. Figure IV 14 shows other ground elevations at various flight line locations.

General Tower Fly-By Instructions.

The following outline is suggested for planning and accomplishing tower fly-by calibrations after the test airplane has been scheduled as prescribed by AFFTC Regulation 55-15.

Engineer's Checklist.

Preparations (day before flight)

1. Check with the Maintenance Control Section on status and availability of the test airplane.

2. Notify the Maintenance Control Section of scheduled tower fly-by and request a preflight instrumentation check. Request an airspeed system leak and continuity check if the leak check is required.

3. Check with weather forecaster (ext 4472) to obtain a prediction of wind or other weather conditions (optional).

4. Determine the speed range to be covered and prepare the pilot's and tower observer's cards. Figure IV 10 is a sample of the pilot's data card and figure IV 9 is the sample of the tower observer's data card.

5. Obtain flight line pass, Polaroid camera (optional), and observation tower key.

<u>Preflight Phase</u>.

1. Brief and provide pilot with flight card.

2. Obtain altimeter(s) reading at the airplane and record on data card, figure IV 9.

<u>Flight Phase</u>.

1. Record the following information on the data card after each pass:

a. Time of day.

b. Theodolite reading.

c. Altimeter(s) reading.

d. Free air temperature.

e. Aim airspeed.

2. Inform pilot if fly-by pass is too high or too low, or make any comments considered necessary such as weather and traffic conditions. All fly-by passes should be conducted higher than the zero grid reading, which is 35 feet above the ground, to insure that the test airplane is not in ground effect. As a general rule, fly-by passes are conducted at a height above the ground greater than one wing span of the test airplane.

3. Remind pilot to obtain ground block records after landing.

Postflight Phase.

1. Record landing time and runway used.

2. Remind pilot to obtain postflight ground block record.

3. Obtain altimeter(s) reading at the location where the airplane has been parked.

4. Notify the instrumentation personnel of flight termination and request postflight check.

5. Obtain weather barometric pressure record requested earlier.

6. Obtain pilot's data card (figure IV 10).

Pilot's Checklist.

Preflight

1. Refer to ARPS Manual, AFFTC-TN-59-47, for pilot flight techniques.

2. Check instrumentation operation instructions in the T.O. located at Flight Test Operations.

3. Set cockpit altimeter at 29.92 in. Hg.

4. Check the operation of instrumentation installed in aircraft.

5. Obtain altimeter ground block record at the ramp and prior to brake release. Record on figure IV 10 as required.

Flight Phase.

1. Fly the tower fly-by pattern as shown in figure IV 15.

2. Record the following data obtained when the airplane passes opposite the observation tower (figure IV 10):

a. Correlation Counter Number.

b. Airspeed.

c. Altitude.

d. Free air temperature.

e. Configuration.

f. Remarks.

Postflight.

1. Obtain ground block upon leaving runway and when parking airplane. Record time and location.

2. Operate instrumentation prior to engine shutdown to obtain a record of data on the ground.

3. Record any other appropriate comments or remarks.

Instructions for the East Askania Tower Facility.

Prepare tower for fly-bys by doing the following:

a. Turn radio on and allow a few seconds for warmup. Request, through Comm Switch, the desired radio channel; usually, the tower frequency, Channel 1 (236.6).

b. Open windows.

c. Lower peep sight into position.

d. Lower theodolite window grid into position.

e. Place mercury thermometer outside to obtain ambient temperature (optional).

f. Call the Base Weather Station (Ext 3723) and request that barometric pressure readings be recorded every 15 minutes if weather data is desired. The weather recordings should cover a period of approximately one-half hour before takeoff to one-half hour after the test airplane had landed.

Ground Block Tower Fly-By Data Reduction Outline.

Before starting the tower fly-by data reduction, accomplish the following:

1. Apply instrument corrections to all altimeter ground block readings recorded on figure IV 9 (tower observer's data) and to the ground block readings recorded on figure IV 10 (pilot's card).

2. Reference all instrument corrected ground block readings to the zero grid by refering to figure IV 13. Care must be taken to account for the altimeter height above the ground in the particular aircraft installation.

3. Plot all ground block data versus time of day as shown in figure IV 16.

4. Plot the base weather station barometric pressure ($P_{a_{wx}}$) on same plot as the ground blocks, figure IV 16 (optional).

5. Fair individual ground block lines for each test altimeter in the airplane to reflect the barometric pressure change that occurred during the period that the fly-bys were being conducted. Use the altimeter readings recorded in the fly-by tower to help determine the most realistic barometric pressure change trend. The dotted lines in figure IV 16 indicate the ground block pressure change for each test altimeter in the airplane. The test instruments installed in the airplane are the only instruments which are utilized in obtaining the airspeed system calibration by the ground block method.

TOWER FLY-BYS

OBSERVER'S DATA

DATE: ______________ RADIO CALL: ______________

AIRCRAFT: ______________ S/N: __________ (TOWER: FREQ.: 318.1 MC.,CHAN. 2)

PHONE EXT.:

WEATHER	3723
TEST OPERATIONS	3133
INSTRUMENTATION	4576

PREFLIGHT (AT AIRPLANE)

ALTIMETER SETTING 29.92 IN. HG.

TIME	TOWER ALTIMETER(S) S/N	S/N	S/N	S/N	LOCATION

TAKEOFF TIME: __________ RUNWAY __________

TOWER DATA:

PASS NO.	TIME	TOWER ALTIMETER(S) S/N	S/N	S/N	TOWER READING HT	AIM AIRSPEED	FREE AIR TEMP.	CONFIG	REMARKS
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

LANDING TIME: __________ RUNWAY __________

POST FLIGHT (AT AIRPLANE)

TIME	TOWER ALTIMETER(S) S/N	S/N	S/N	S/N	LOCATION

Figure IV 9 OBSERVER'S DATA CARD

TOWER FLY-BYS

AIRCRAFT: ____________ S/N ____________ FLT. NO. ____________
PILOT ____________ DATE ____________
OBSERVER ____________ T.O.TIME: ____________ R/WAY ____________
AIRSPEED IND.NO. ____________ LAND'G TIME: ____________ R/WAY ____________
ALTIMETER NO. ____________ SETTING 29.92 IN.HG.

GROUND BLOCKS:			
LOCATION:	TIME	ALTITUDE	CTR. NO.
RAMP: AFTER ENGINE START			
TAKEOFF: BEFORE BRAKE RELEASE			
LANDING: END OF RUNWAY OR C. TAXIWAY			
RAMP: BEFORE ENGINE SHUTDOWN			

CTR NO.	AIM IAS	ACTUAL IAS	ALTITUDE	FAT Deg C	CONFIG	REMARKS						

Figure IV 10 PILOT'S DATA CARD

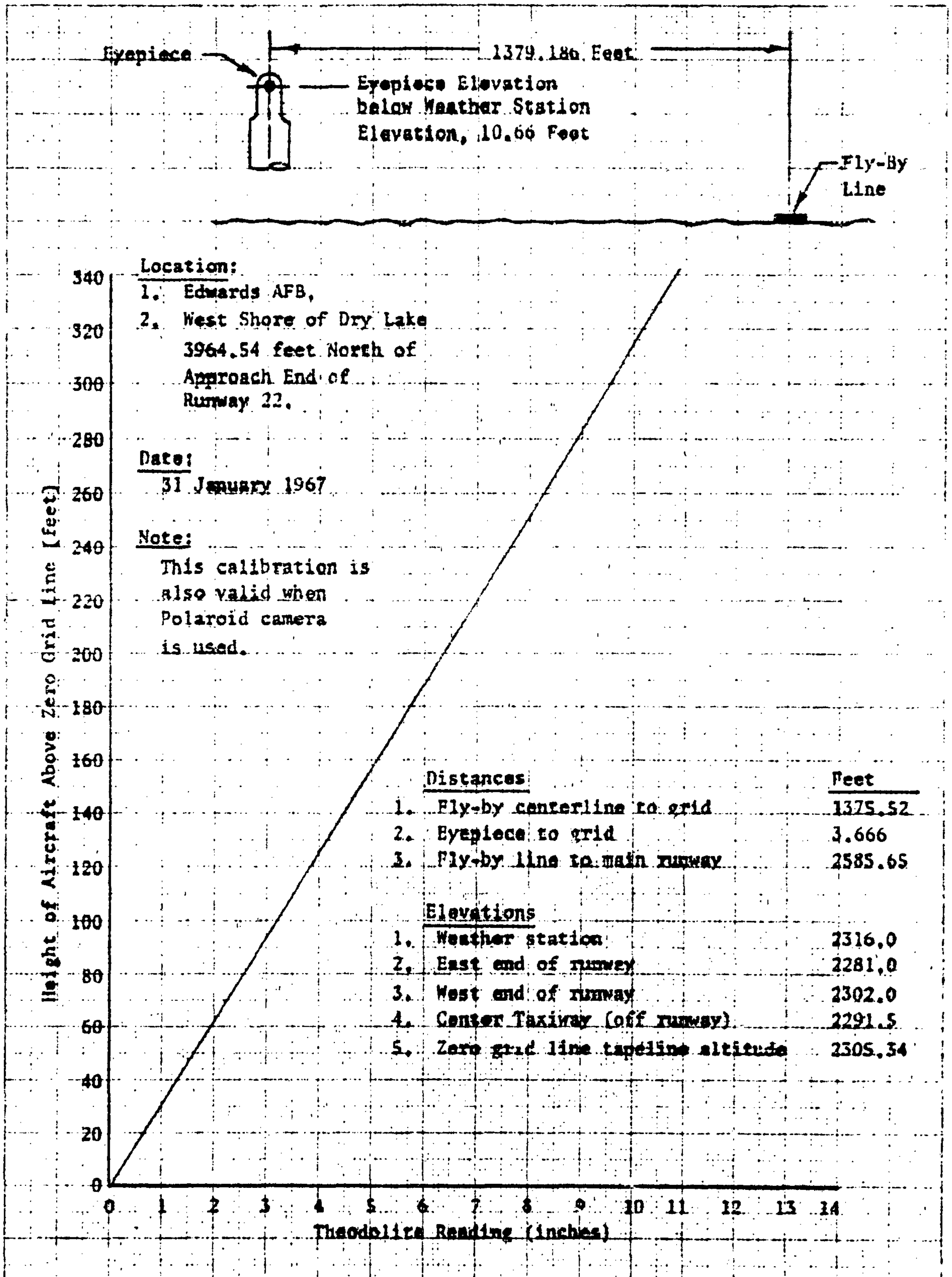


Figure IV 11. Fly-By Tower Theodolite Calibration

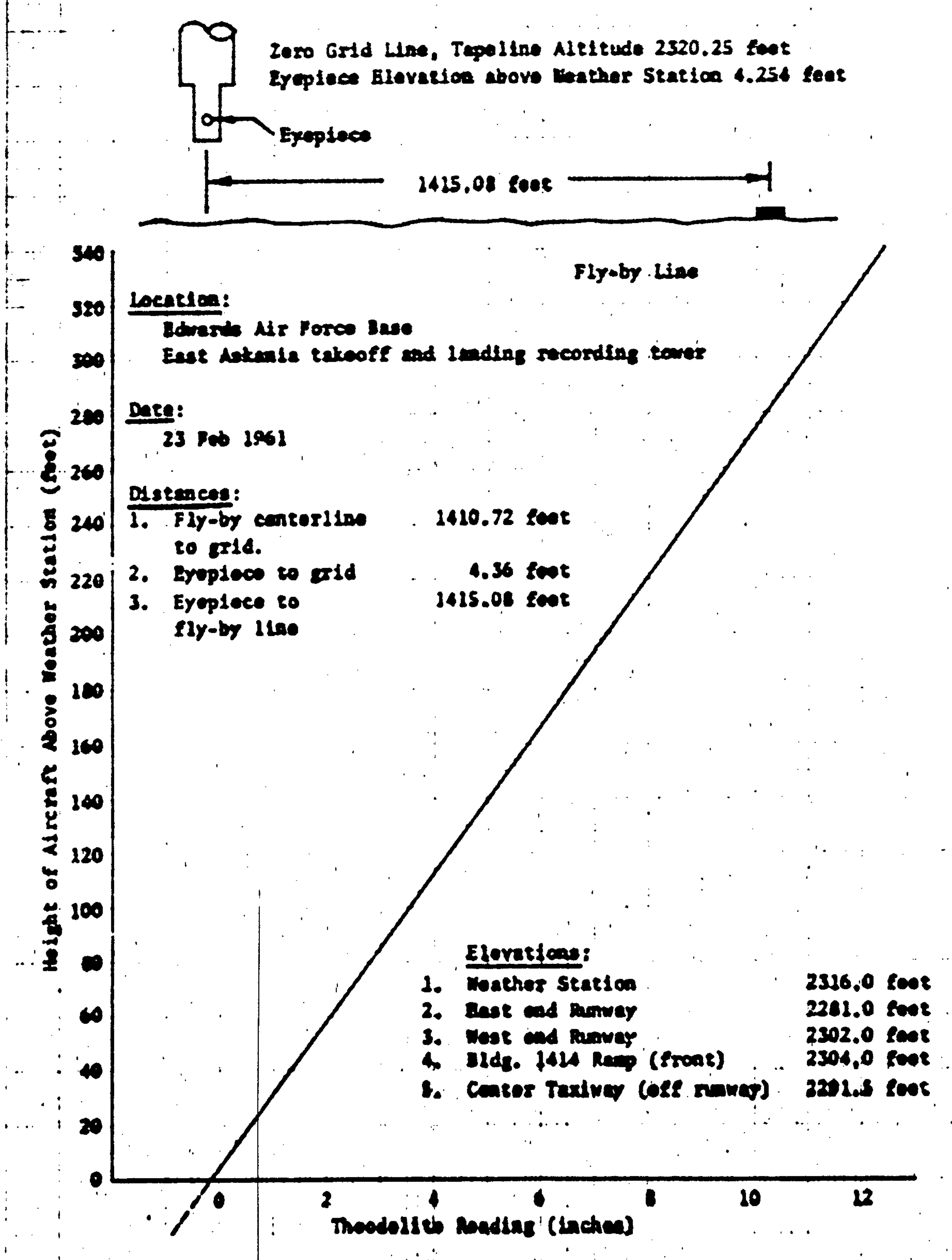


Figure IV 12 East Askania Tower Fly-By Theodolite Calibration

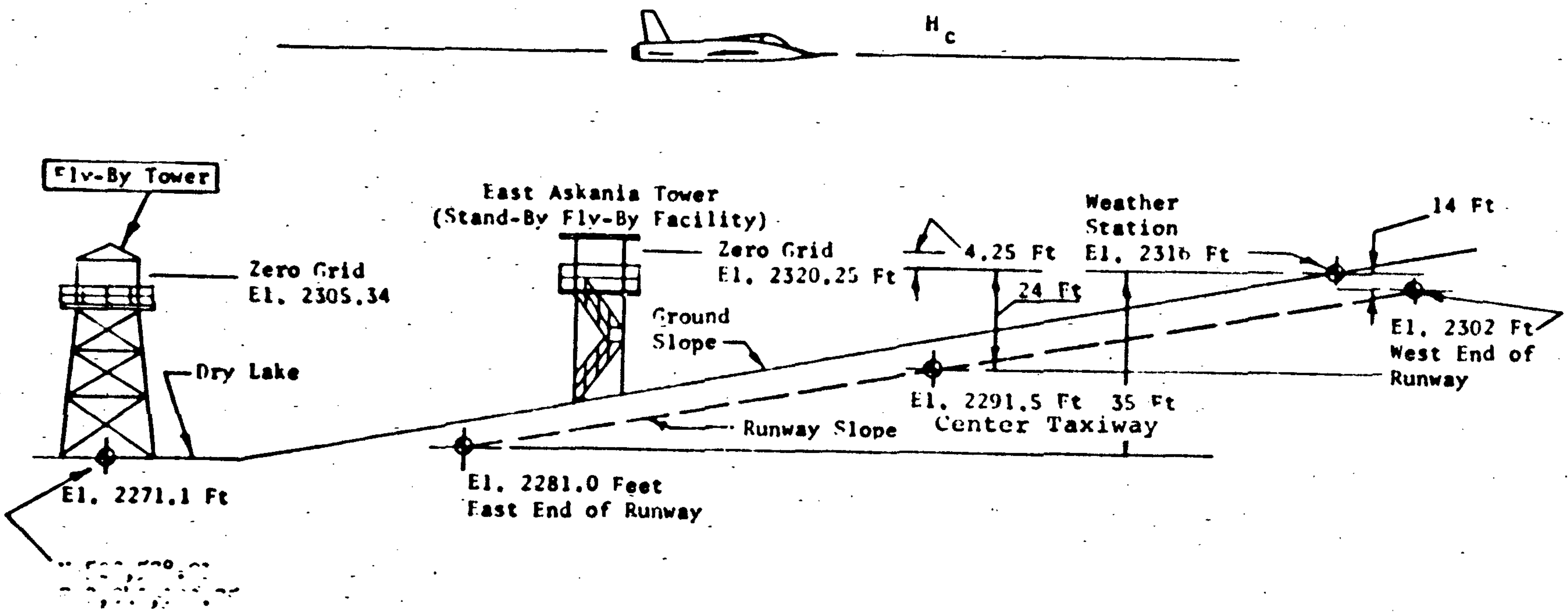


Figure IV 13 TOWER FLY-BY ELEVATIONS INFORMATION

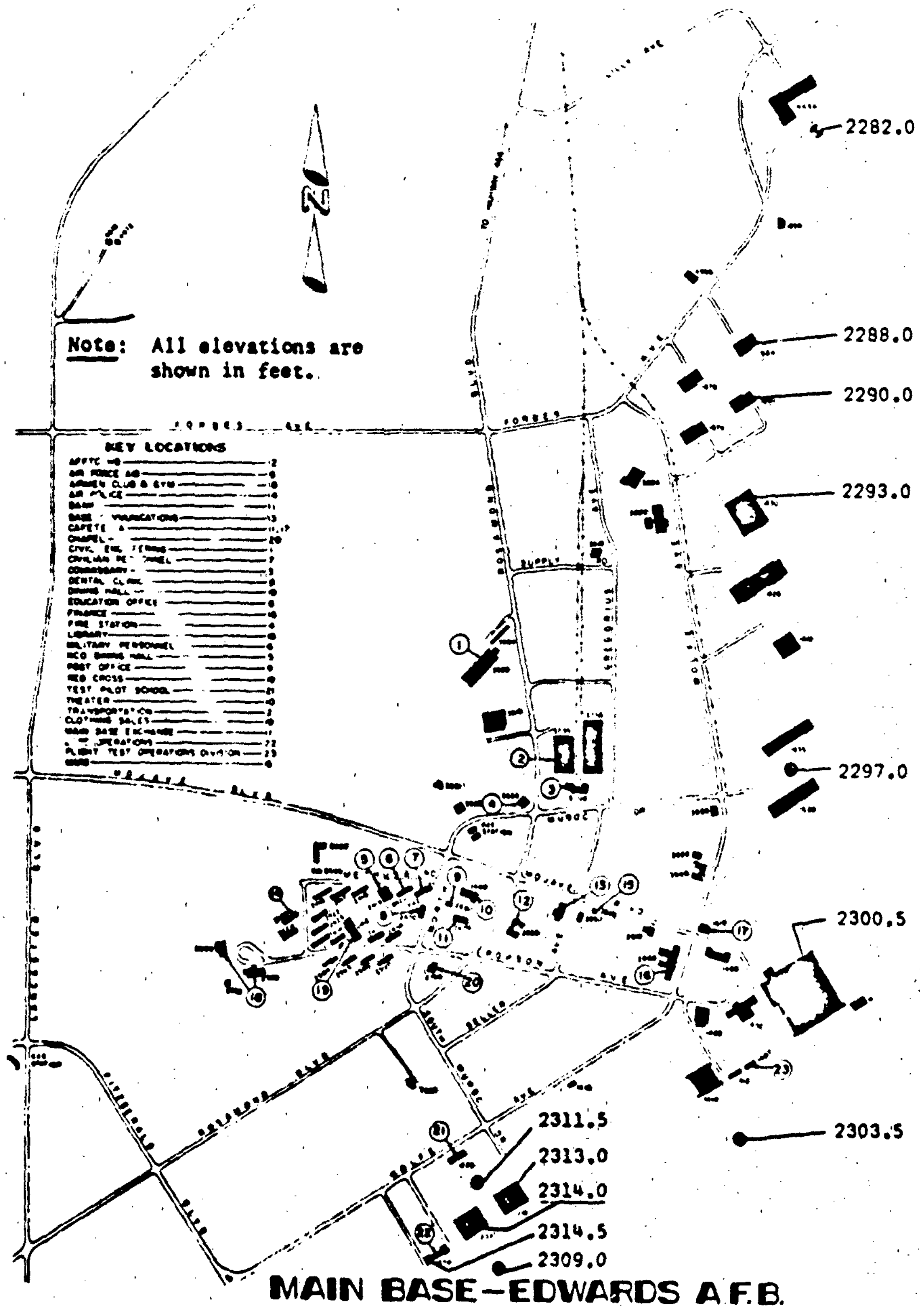


Figure IV 14 (GROUND EVEVATIONS INFORMATION FOR TOWER FLY-BYS)

TOWER FLY-BY PATTERN

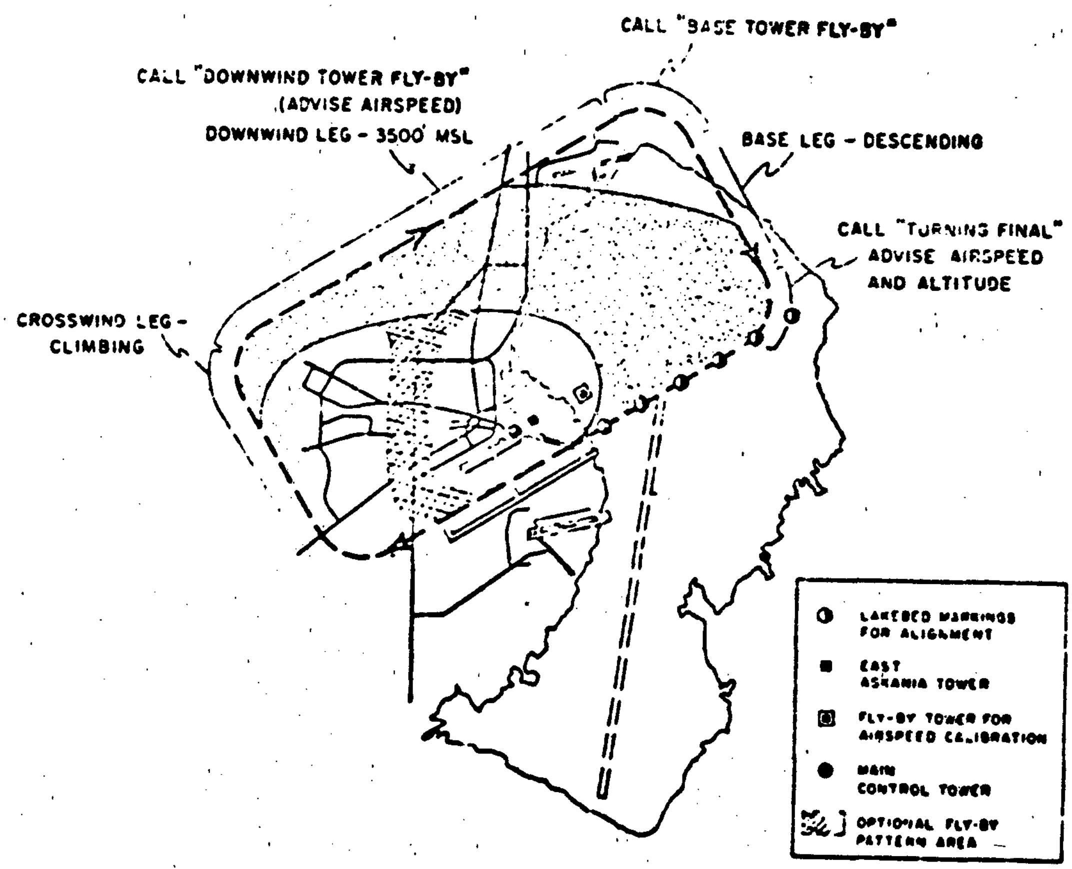


Figure IV 15 TOWER FLY-BY PATTERN

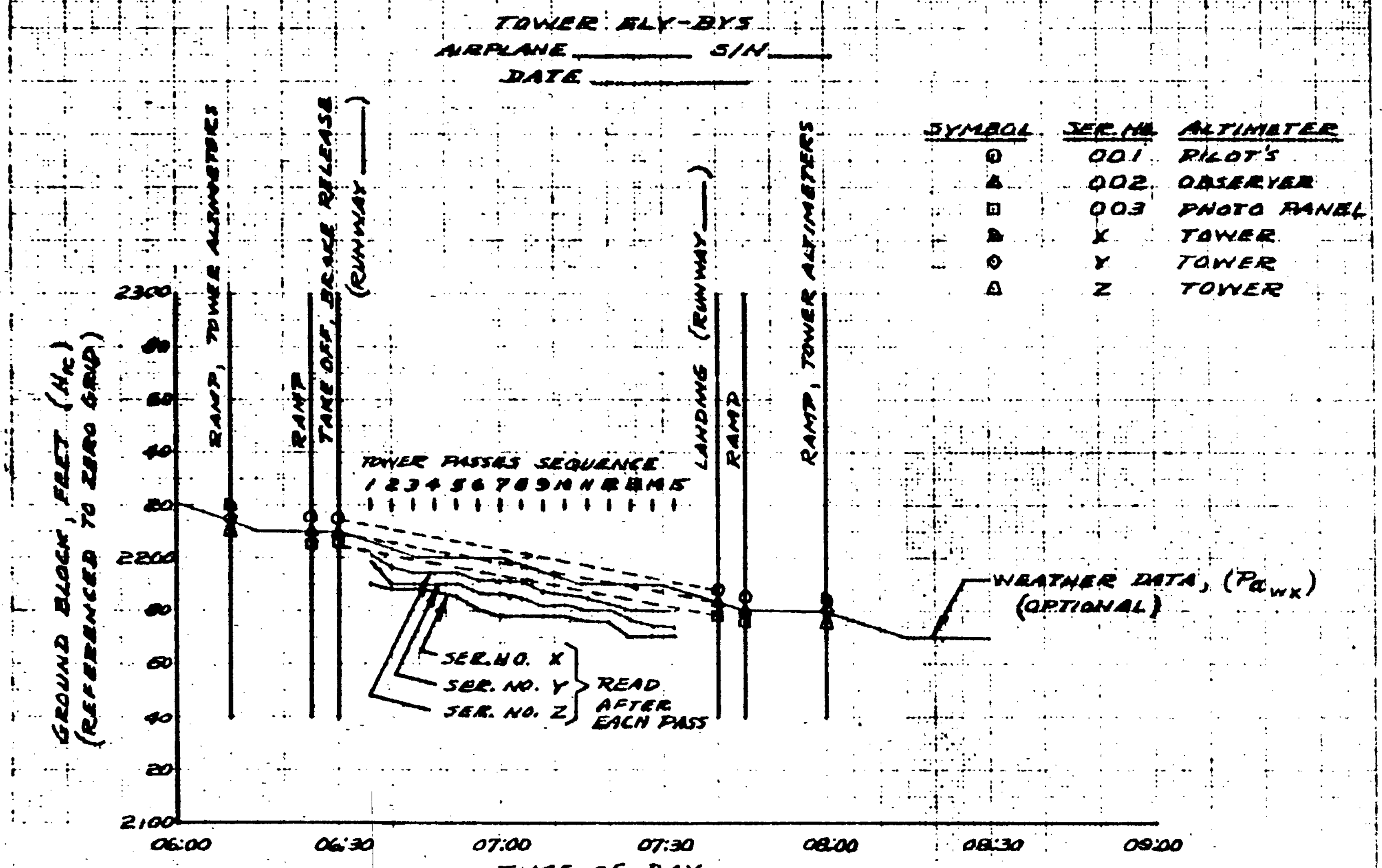


FIGURE IV 16 GROUND BLOCK ALTIMETER READINGS

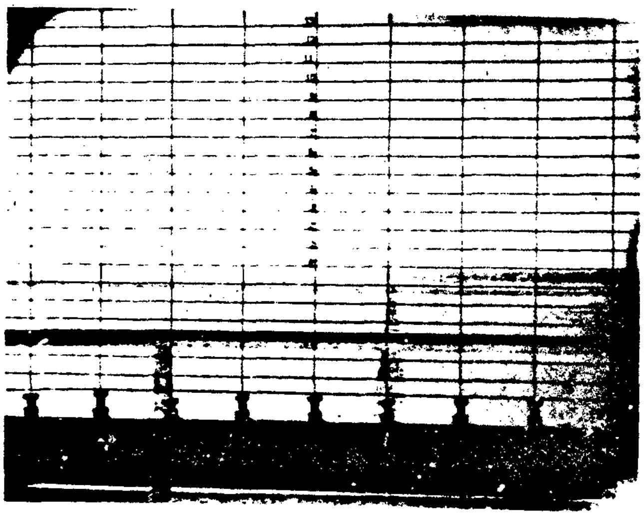


Figure IV 17 TOWER FLY-BY DATA PICTURE

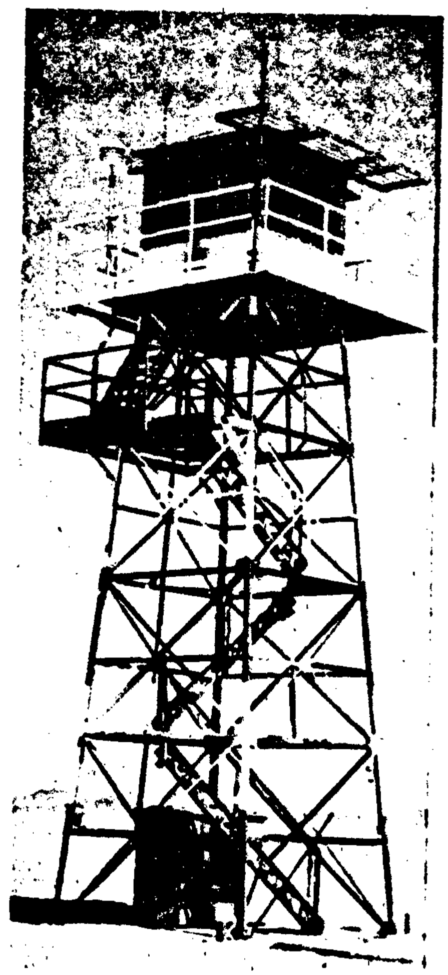


Figure IV 18 FLY-BY TOWER

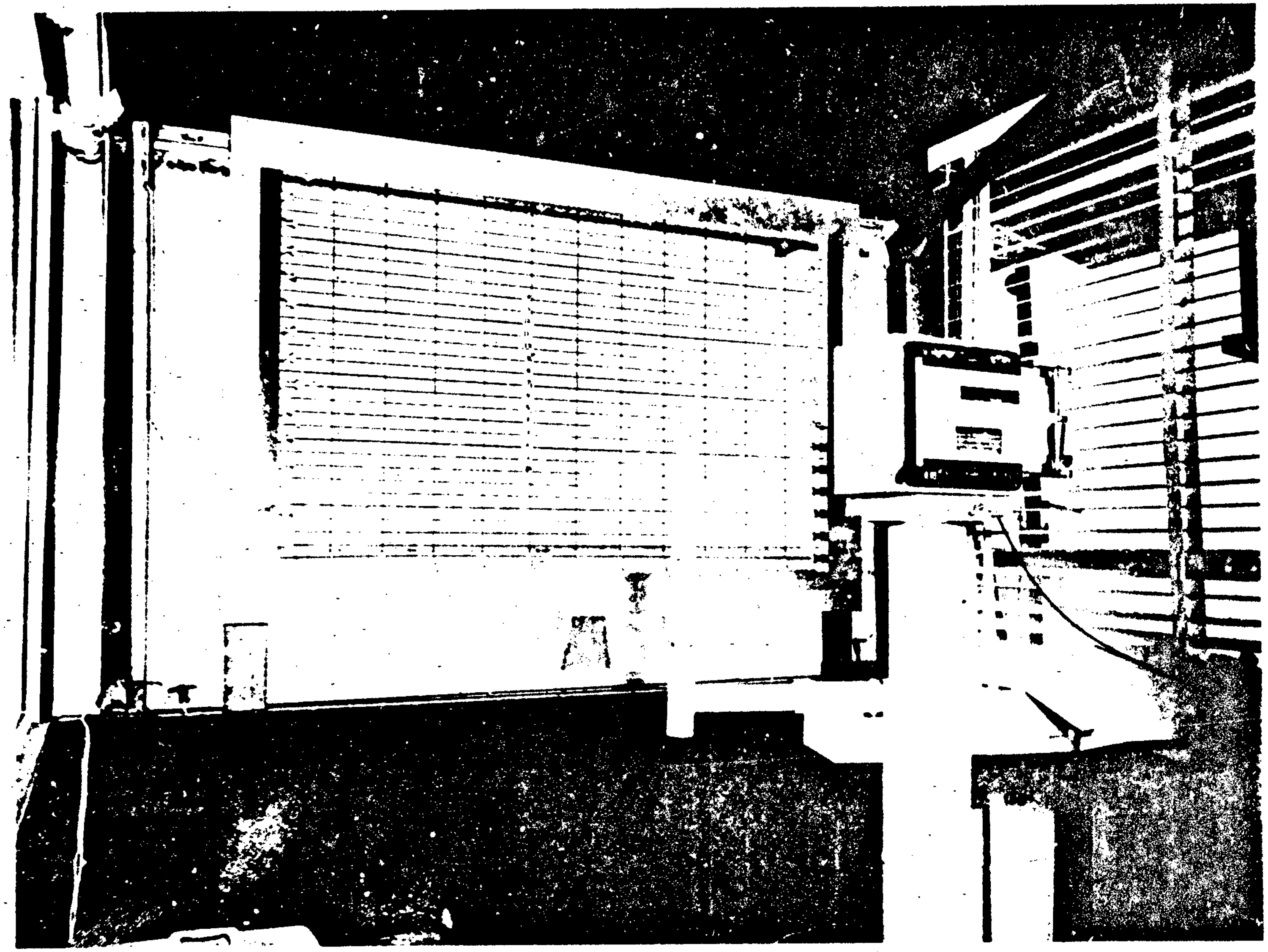


Figure IV 19   FLY-BY TOWER DETAILS

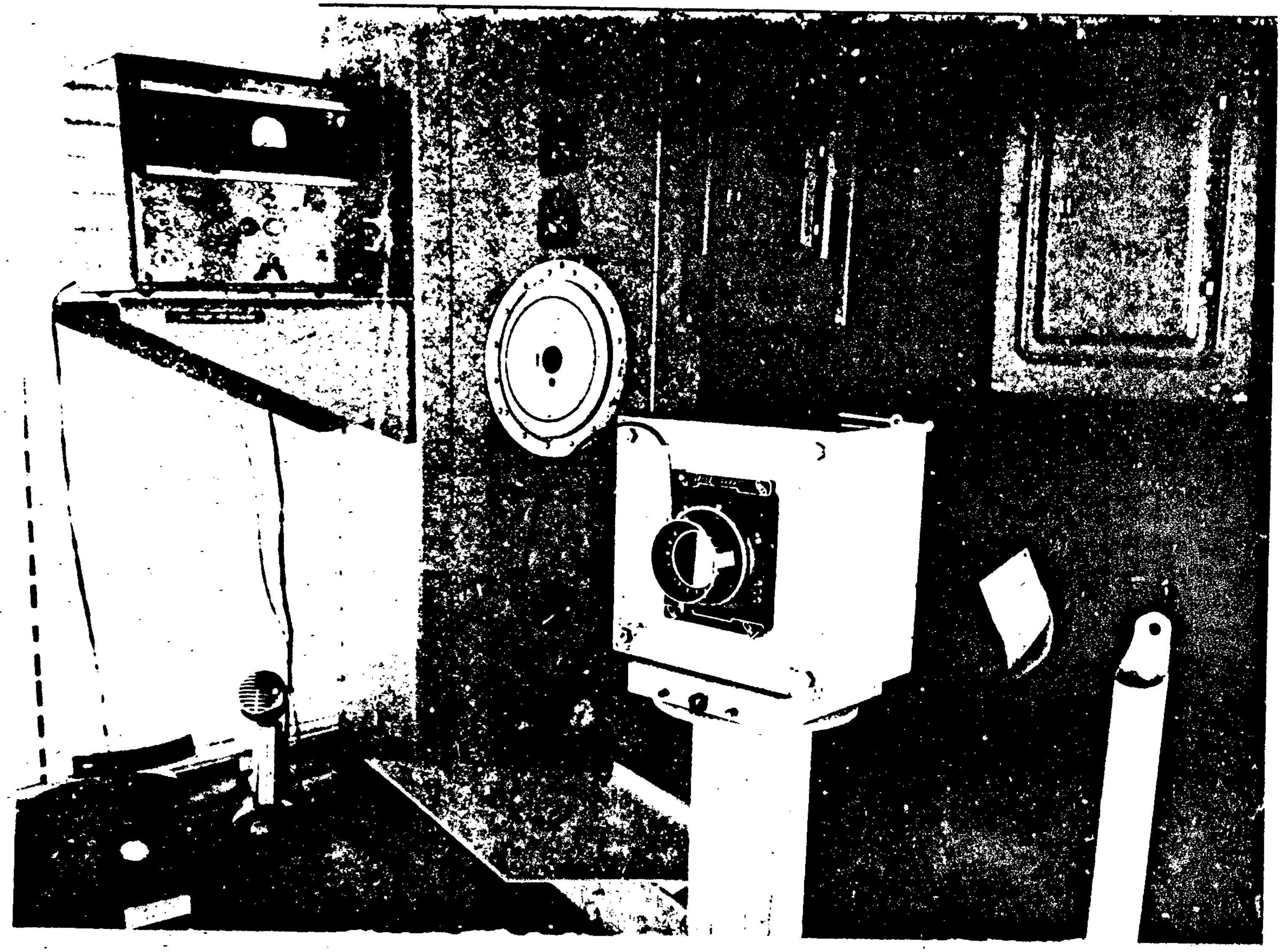


Figure IV 20 FLY-BY TOWER DETAILS

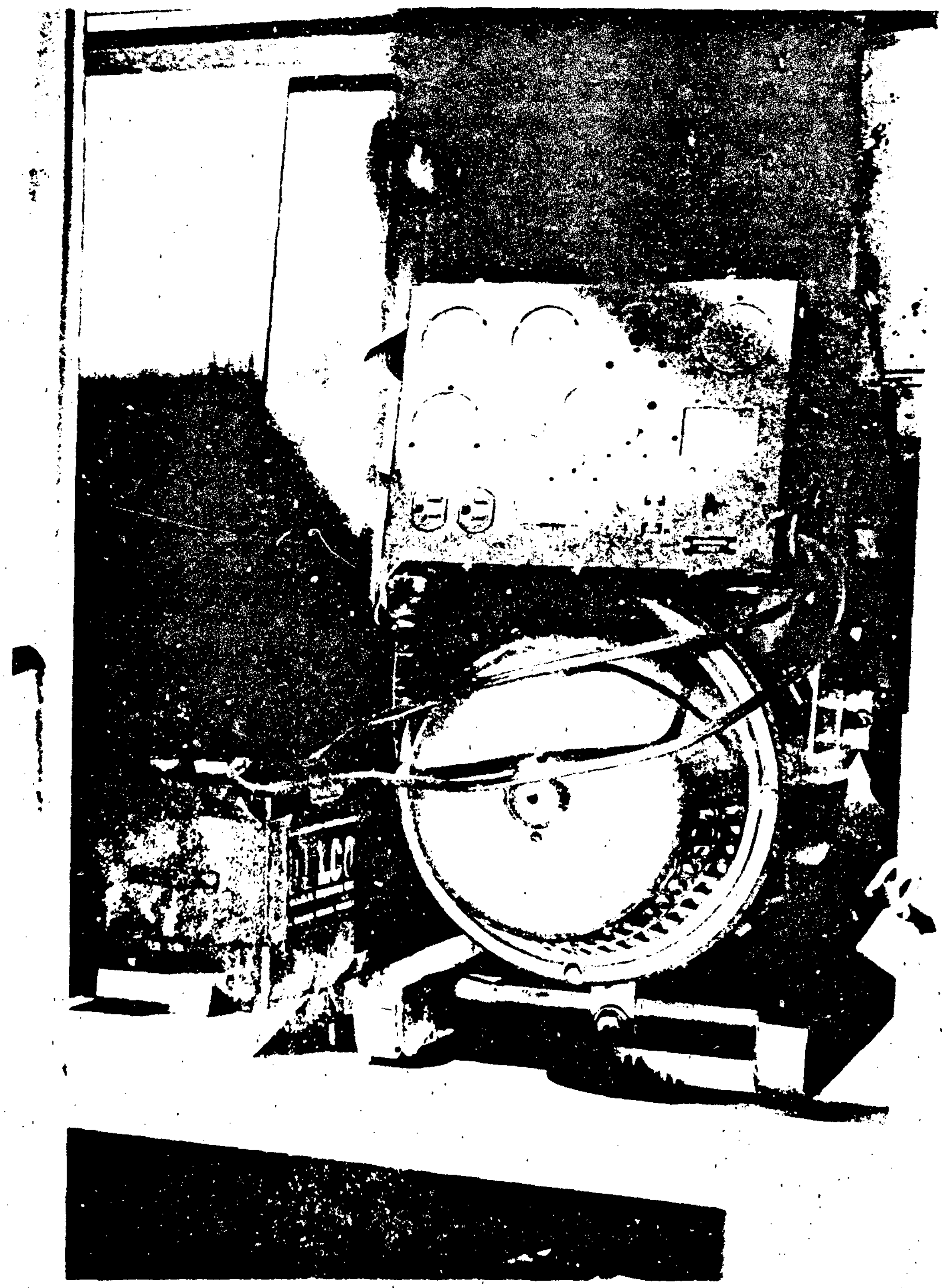


Figure IV 21 FLY-BY DETAILS

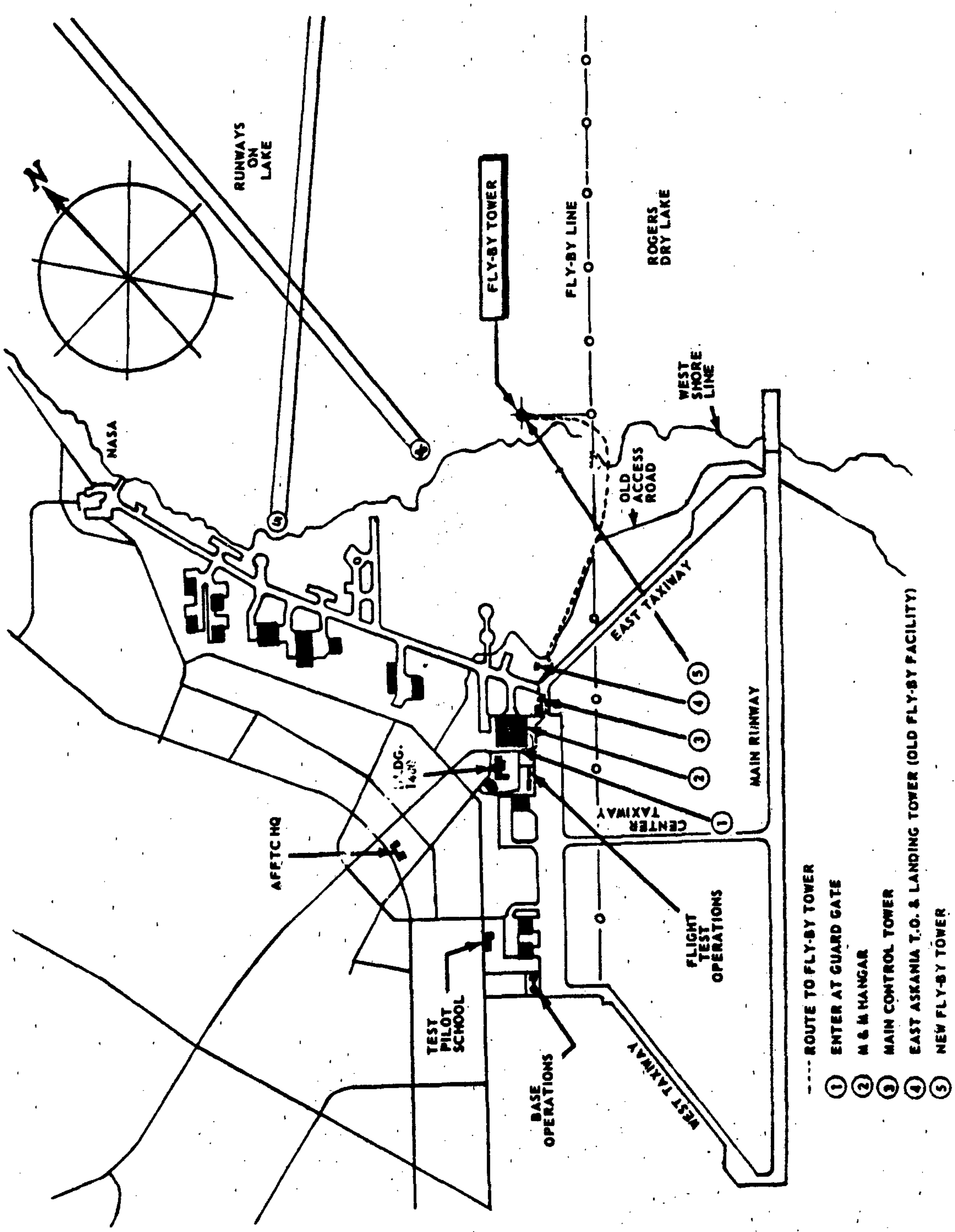


Figure IV 22 FLY-BY TOWER LOCATION

Data Reduction Outline:

In this outline provisions are made for three altimeters and three airspeed indicators such as pilot's, observer, and on-board recorder.

Step	Parameter	Unit	Description	
1	Point No.	----	Sequence	
2	Counter No.	----	Correlation between pilot and on-board recorder data	
3	Time	hrs and min	Time of day	
4	V_{i_1}	knots	Indicated airspeed (pilot's)	Three airspeed indicators manifolded to the same system
5	V_{i_2}	knots	Indicated airspeed (observer)	
6	V_{i_3}	knots	Indicated airspeed (photopanel)	
7	H_{i_1}	feet	Indicated altitude (pilot's)	Three altimeters manifolded to the same system
8	H_{i_2}	feet	Indicated altitude (observer)	
9	H_{i_3}	feet	Indicated altitude (recorder)	
10	V_{ic_1}	knots	4 + Instrument correction (ΔV_{ic})	
11	V_{ic_2}	knots	5 + Instrument correction (ΔV_{ic})	
12	V_{ic_3}	knots	6 + Instrument correction (ΔV_{ic})	
13	H_{ic_1}	feet	7 + Instrument correction (ΔH_{ic})	
14	H_{ic_2}	feet	8 + Instrument correction (ΔH_{ic})	
15	H_{ic_3}	feet	9 + Instrument correction (ΔH_{ic})	
16	$V_{ic_{avg}}$	knots	$\frac{10 + 11 + 12}{3}$, Average indicated airspeed	

Step	Parameter	Unit	Description
17	$H_{ic_{avg}}$	feet	$\frac{(13) + (14) + (15)}{3}$, Average
18	$M_{ic_{avg}}$	----	Mach number 16 and 17
19	T.R.	inches	Theodolite grid reading
20	H_t	feet	19 Converted using theodolite calibration, figure IV 11
21	$G.B._1$	feet	From plot of ground block reading versus time of day, figure IV 16. Altimeter No. 1
22	H_{c_1}	feet	20 + 21 Pressure altitude, Altimeter No. 1
23	ΔH_{pc_1}	feet	22 - 13 , Altimeter position corrections, Altimeter No. 1
24	$G.B._2$	feet	From figure IV 16, ground block, Altimeter No. 2
25	H_{c_2}	feet	24 + 20 , Pressure altitude, Altimeter No. 2
26	ΔH_{pc_2}	feet	25 - 14 , Altimeter position correction for Altimeter No. 2
27	$G.B._3$	feet	From figure IV 16, ground block, Altimeter No. 3
28	H_{c_3}	feet	27 + 20 , Pressure altitude, Altimeter No. 3
29	ΔH_{pc_3}	feet	28 - 15 , Altimeter position correction for Altimeter No. 3
30	$\Delta H_{pc_{avg}}$	feet	(23 + 26 + 29)/3, Average position correction
31	$\Delta M_{pc}/\Delta H_{pc}$	10^{-5} per feet	17 and 18, figure V 9
32	$\Delta M_{pc_{avg}}$	----	31 x 30 , Average position correction (ΔM_{pc})
33	$\Delta M_{pc}/\Delta V_{pc}$	1 per knot	17 and 18 , figure V 6
34	ΔV_{pc}	knots	32 / 33 Position correction

Step	Parameter	Unit	Description
35	$\Delta M_{pc}/\Delta P_q/q_{c_{ic}}$	----	18 figure V 10
36	$\Delta P_p/q_{c_{ic}}$	----	32 / 35 , Position error correction
37	W_t	lb	Engine start gross weight - fuel used
38	$H_{P_{avg}}$	feet	$\frac{22 + 25 + 28}{3}$, Average pressure altitude
39	δ	----	At 38 , from standard altitude tables
40	W/δ	lb	37 / 39
41	M	----	18 + 32 , Mach number
42	M^2	----	(41)^2
43	S	sq ft	Wing area
44	C_L	----	Lift coefficient = $\frac{0.000675 \times 40}{42 \times 43}$

Alternate method for obtaining position error correction (ΔV_{pc}):

Step	Parameter	Unit	Description
45	$\Delta H_{pc}/\Delta V_{pc}$	feet/knot	16 and 17 and figure V 8
46	ΔV_{pc}	knots	30 / 45 average position error correction

Alternate method for obtaining C_L using V_t:

Step	Parameter	Unit	Description
47	S	sq ft	Wing area
48	V_c	knots	Calibrate airspeed 16 + 34 or 46
49	ΔV_c	knots	48 and 17 and figure V 5
50	V_e	knots	Equivalent airspeed, 48 - 49
51	σ	----	17 and standard altitude table
52	$\sqrt{\sigma}$	----	(51)^2

Step	Parameter	Unit	Description
53	V_t	knots	50 / 52
54	V_t^2	knots	$(53)^2$
55	C_L	----	Lift coefficient = $\frac{295 \times 37}{51 \times 54 \times 47}$

3. Pacer Method:

As previously stated, the pitot-static system can also be calibrated by flying the test aircraft and a specially-calibrated pacer airplane abreast of it. Care must be exercised by the pilots to avoid flying too close to the other airplane to avoid the interaction of one airplane's pressure field with that of the other. The pacer method has the advantage of obtaining a large number of data points in a relatively short time at any desired altitude. The main disadvantage is that the accuracy of the results depends on the accuracy of two sets of test instruments as well as on the accuracy of the pacer's position error calibration and the pilot's flight technique.

In this method, data are simultaneously recorded by the pacer and test airplanes with both airplanes stabilized at the same altitude and airspeed. The speed is changed by predetermined airspeed increments to adequately cover the full speed range of the test airplane, usually from fast to slow speed. A second pacer is sometimes used if the first pacer does not adequately cover the flight envelope of the test airplane. A slow speed pacer may have to be used when the test airplane changes from clean to other slower speed test configurations such as power approach, takeoff, or landing. Since the position error of the pacer is known, the pacer calibrated airspeed and altitude can be readily computed. Since the two airplanes are flown in a stabilized condition, the pacer airspeed and altitude are the same as for the test airplane

and therefore the position error for the test airplane can be obtained. Comparison of the altitudes will result in a direct measurement of the static system position error of the test aircraft. Comparison of the airspeeds between the two aircraft will give a measurement of the pitot-static system position error of the test airplane. The position error curve (ΔV_{pc}) from the airspeed comparison should be consistent with the calibration results (ΔV_{pc}) calculated from the altitude comparison. A total pressure error should be suspected if the results of the two methods mentioned differ significantly. The error should be considered significant if the magnitude of the error cannot be attributed to normal instrument error.

Total pressure error is checked by calculating the total pressure (P_{t_o}) of the pacer and test airplane. The results are plotted as shown in figure IV 31. Ideally the resulting calculated P_{t_o} for both airplanes should be the same if no total error exists. The total pressure calculations are accomplished utilizing the following equation $P_{t_o} = P_{a_{ic}} + P_{c_{ic}}$; where $P_{a_{ic}}$ is obtained from values of indicated altitude (H_{ic}) and altitude tables. Values of $q_{c_{ic}}$ are obtained from indicated airspeed (V_{ic}) and utilizing table 9.6 presented in reference 1, pages 321 to 335. The following equations are the basis for the pacer method:

$$\Delta H_{pc_{test}} = H_{c_{pacer}} - H_{ic_{test}}$$

$$\Delta V_{pc_{test}} = V_{c_{pacer}} - V_{ic_{test}}$$

Definition of each term is given in the data reduction outline.

The following outline is suggested for planning and accomplishing an airspeed calibration by the pacer method:

Engineer's Checklist.

Preparation

1. Schedule the pace flight through Center Scheduling on Form 16.

a. Provide all necessary information such as date, time airplanes involved, radio frequency required, etc.

b. On the weekly schedule (Form 16), request a weather balloon be released if balloon temperature data are required for determination of the test temperature probe recovery factor. Balloon temperature data will be used under the assumption that the high altitude (above 35,000 feet) ambient temperature will remain constant over a large area and a long period. The balloon release should be accomplished a short time before the flight is to be conducted.

c. Check maintenance status of pacer and test airplanes. Notify the Maintenance Control Section of the scheduled pace and request an instrumentation preflight check for both pacer and test airplanes. An airspeed system leak and continuity check should be requested at this time if desired.

2. Prepare flight cards for both airplanes (see figure IV 23).

a. Select airspeed points to be flown keeping in mind the flight envelope capabilities of both airplanes.

Preflight

1. Brief pilots and observers (if applicable) on all necessary details of proposed pace flight. Hand signals should be used

in case radio communication fails. (Detailed instructions on flight techniques are provided in the ARPS Manual, AFFTC-TN-59-46, 1959, page 1-20, reference 2.)

Flight Phase (Project Engineer or Observer)

1. Set altimeter(s) at 29.92 in. Hg.

2. Operate any instrumentation required to record test data.

3. Record test data (figure IV 23).

4. Provide event marks for identification of data.

5. Record any significant remarks or observations.

Postflight

1. Hold postflight briefing.

2. Obtain data card(s) pilot or observer.

3. Check all recorded data carefully.

4. Request an instrumentation postflight check as required.

Pilot's Checklist.

Preflight

1. Check status of airplane.

2. Hold briefing with project engineer.

3. Obtain flight test data cards.

Flight Phase

Use same checklist as used by the project engineer when acting as observer.

Postflight

1. Hold postflight briefing with project engineer.

2. Review all recorded calibration data with project engineer.

3. Provide any remarks or details required for explanation of recorded data.

General Remarks.

Figure IV 24 is a diagram of a former AFFTC pacer airspeed system. The main airspeed system (No. 1, nose boom) utilized three altimeters and three airspeed indicators. Three instruments were utilized to improve accuracy and reliability. The other airspeed systems were backup systems. These backup systems had a twofold purpose, they were utilized as a cross check of the number one system and as a secondary system to be used in case of a malfunction of the primary system. After every pace the pacer pilot would obtain a cross check of the three systems by recording the indicated airspeeds of the three airspeed indicators in the cockpit. A malfunction occurring in any one of the three pacer airspeed systems would be readily apparent since the indicated value would be different from the other two systems.

Since the airspeed indicator and altimeter were connected to a mutual static pressure source, ΔV_{pc} and ΔH_{pc} were related as shown in figure V 8. In all cases the position error callibration would be calculated from the values obtained from both the

altimeters and the airspeed indicators. A typical airspeed calibration for nose boom installation is shown in figure IV 25.

TEST DATA

Pacer Acft. ____________ S/N ____________ Date ____________
Pilot ____________ Observer ____________
Takeoff ____________ Landing ____________
Altimeter No. ____________ Setting: 29.92 in. Hg
Airspeed Ind. No. ____________ AIM Alt. ____________ Feet
Test Airplane ____________ Ser No. ____________

AIRSPEED CROSS CHECK: (PACER)

No. 1 Syst.					
No. 2 Syst.					
No. 3 Syst.					

REMARKS:

No.	Cntr No.	AIM Airspeed	Airspeed Vi	Altitude Hi	OAT ti, °C	Pacer Config	Remarks	V_{i_c}	H_{i_c}	ΔV_{pc}	$\frac{dh}{dV}$	ΔH_{pc}	V_c	H_p	H_{ic} or H_c	t_a	

Figure IV 23 PACE DATA CARD

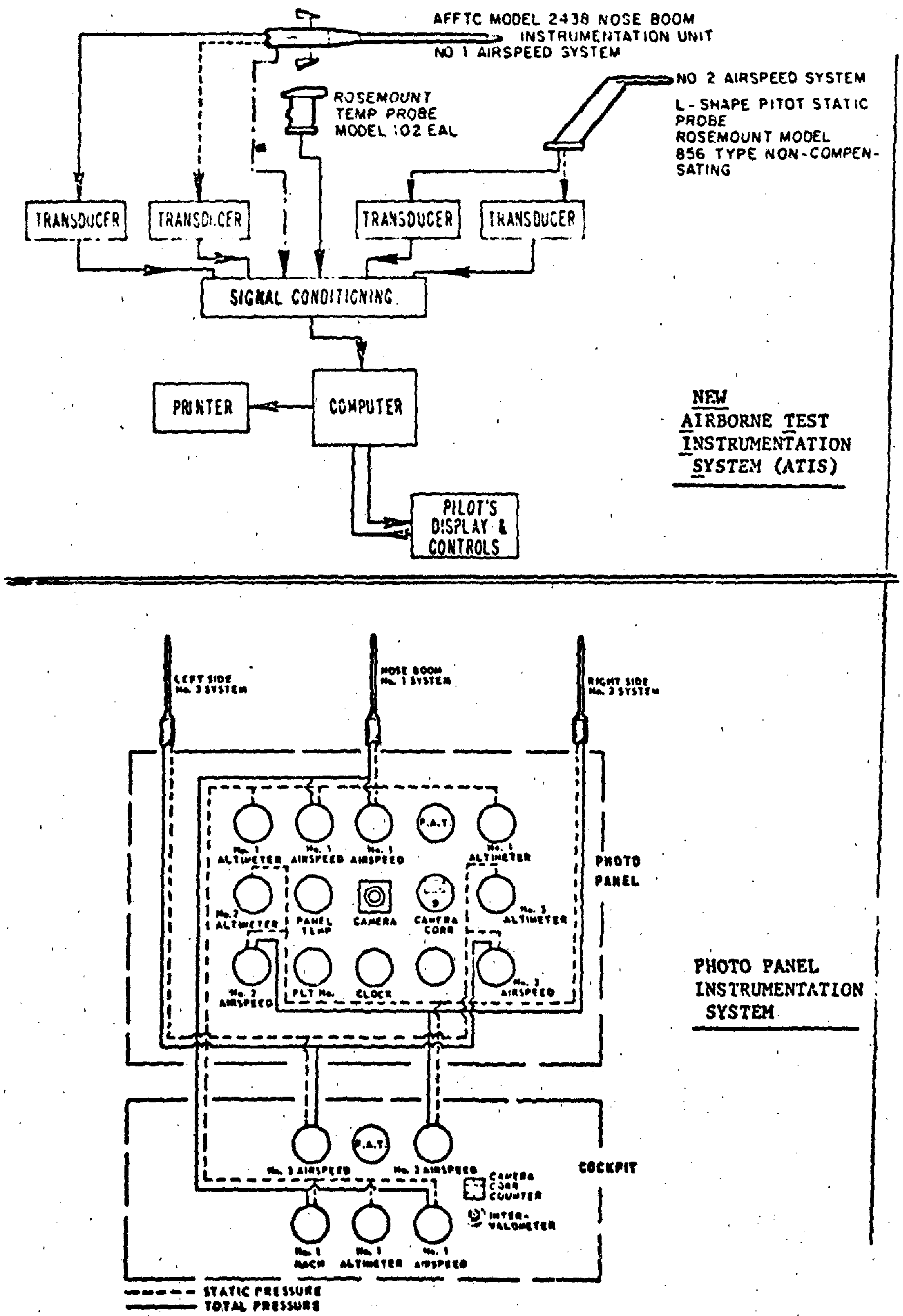


Figure IV 24 PACER INSTRUMENTATION

Standard Airspeed System
F-104A USAF S/N 56-748
Wing Tiptanks Installed
Nose Boom

Symbol	Date	Test	Altitude, Feet	Configuration
◇	30 July 63	Tower Fly-Bys	2,300	Cruise
⊡	6 Aug 63	Tower Fly-Bys	2,300	Cruise
⊙	8 Aug 63	Tower Fly-Bys	2,300	Cruise
▲	13 Aug 63	Tower Fly-Bys	2,300	Cruise
◺	15 Aug 63	Tower Fly-Bys	2,300	Takeoff Flaps
△	29 Aug 63	Pace	25,000	Cruise
⬠	29 Aug 63	Pace	35,000	Cruise
θ	29 Aug 63	Smoke Trail Accel.	35,000	Cruise

Note:
1. Tail denotes takeoff flaps.
2. Ground block method used for all tower fly-bys.

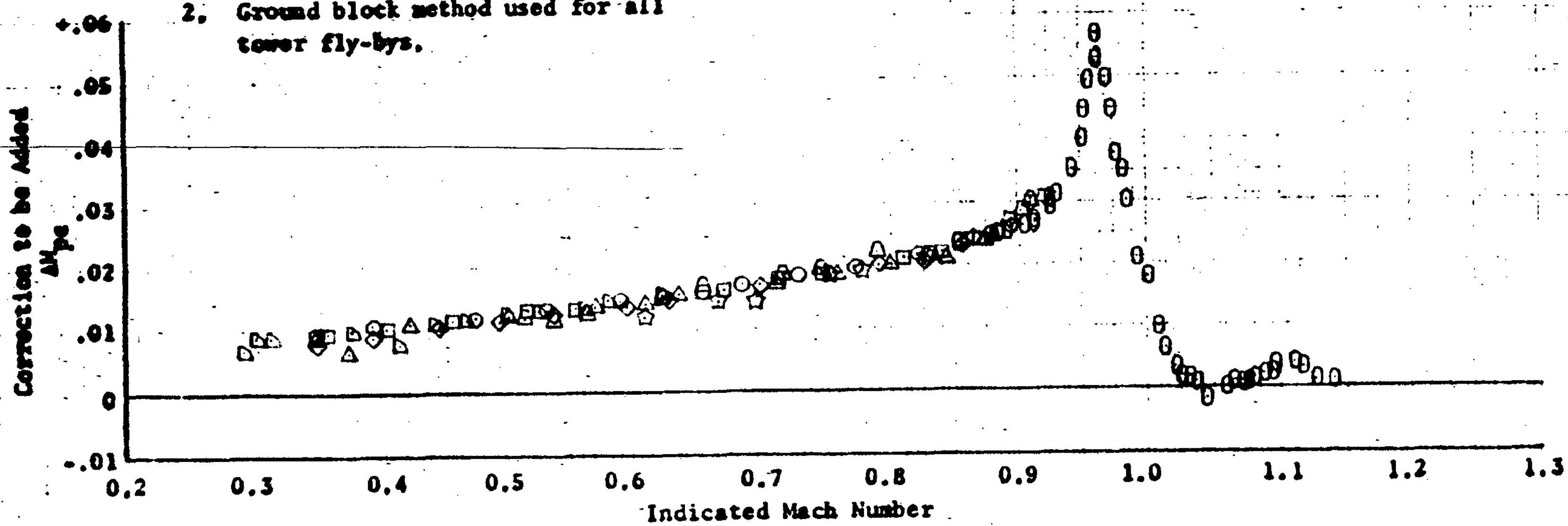


Figure IV 25 Typical Nose Boom Airspeed Calibration

Standard Airspeed System
F-4C USAF S/N 63-7519
No External Stores
Cruise Configuration

Symbol	Test	Altitude (ft)	SPC	Avg Weight (lb)	Avg W/δ (lb)
△	Tower Fly-by	2 300	Off	35 000	38 060
⬠	Pace	10 000	Off	35 000	50 890
▽	Pace	20 000	Off	37 000	80 520
⬭	Pace	30 000	Off	36 500	122 940
◇	Pace	40 000	Off	35 000	204 080

Note:
This calibration is an example of a flush static pressure sensing port installation.

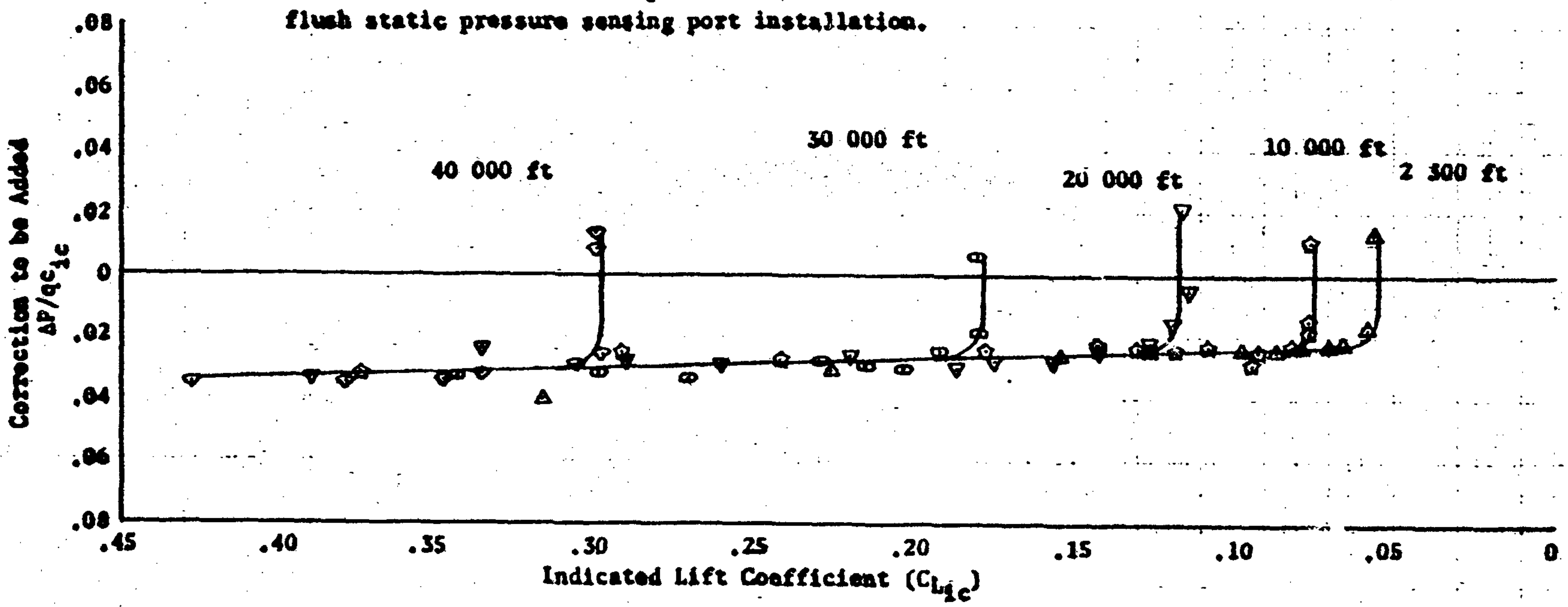


Figure IV 26 Airspeed Calibration (Flush Static Port)

Data reduction outline for the pacer method utilizing the altimeters. Subscripts p or t refer to pacer or test aircraft.

Step	Parameter	Unit	Description
1	Point No.	----	
2	Counter No.	----	Correlation
3	V_{ip}	knots	Indicated airspeed
4	ΔV_{ic_p}	knots	Airspeed indicator instrument correction
5	V_{ic_p}	knots	3 + 4, Airspeed corrected for instrument error
6	H_{ip}	feet	Indicated altitude
7	ΔH_{ic_p}	feet	Altimeter instrument correction
8	H_{ic_p}	feet	6 + 7, Altitude corrected for instrument error
9	M_{ic_p}	----	From 5 and 8, Mach number Chart 8.5 in reference 1 (AFTR 6273)
10	ΔM_{pc_p}	----	Pacer position error calibration at 9
11	$(\Delta M_{pc}/\Delta H_{pc})_p$	10^{-5}/feet	Figure V 9 in Appendix, and steps 8 and 9
12	ΔH_{pc_p}	feet	10 / 11 , Position correction
13	H_{p_p}	feet	8 + 12 , Pressure altitude
14	$(\Delta M_{pc}/\Delta V_{pc})_p$	1/knot	Figure V 6 in Appendix and steps 8 and 9
15	ΔV_{pc_p}	knots	10 / 14 , Position correction
16	V_{c_p}	knots	5 + 15 , Calibrated airspeed
17	M_{c_p}	----	9 + 10 , Calibrated Mach number
18	Vi_t	knots	Indicated airspeed
19	ΔV_{ic_t}	knots	Airspeed indicator instrument correction
20	V_{ic_t}	knots	Airspeed corrected for instrument error, 18 + 19

Step	Parameter	Unit	Description
21	Hi_t	feet	Indicated altitude
22	ΔHic_t	feet	Altimeter instrument correction
23	Hic_t	feet	Altitude corrected for instrument error, 21 + 22
24	Mic_t	----	From 20 and 23, Mach number
25	$(\Delta M_{pc}/\Delta H_{pc})_t$	10^{-5}/feet	Figure V 9 in Appendix and steps 24 and 23
26	ΔH_{pc_t}	feet	13 - 23, Test position error correction
27	ΔM_{pc_t}	----	25 x 26, Test position error correction
28	$(\Delta M_{pc}/\Delta V_{pc})_t$	1/knots	Figure V 6 in Appendix and steps 23 and 24 for $M_{pc} < 0.04$
29	ΔV_{pc_t}	knots	27 / 28, Test poistion correction (utilizing altimeter data)
30	V_{c_t}	knots	20 + 29, Test calibrated airspeed
31	$\{\Delta M_{pc}/(\Delta P_p/q_{c_{ic}})\}$	----	Figure V 10 in Appendix and step 24 for $M_{pc} < 0.04$
32	$(\Delta P_p/q_{c_{ic}}/)_t$	----	27 / 31, Test position correction
33	Wt_t	pounds	Engine start gross weight less fuel used
34	δ_t	----	Atmosphere tables and 13
35	$(W/\delta)_t$	pounds	33 / 34

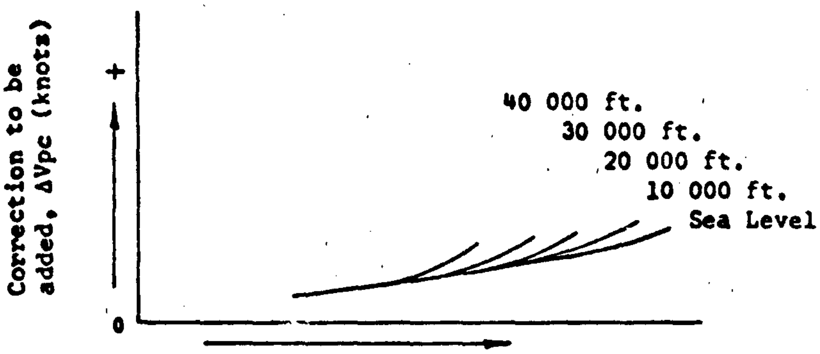
The following steps are used to obtain a calibration utilizing the airspeed indicators:

Step	Parameter	Unit	Description
36	ΔV_{pc_t}	knots	16 - 20, Test position error correction (utilizing airspeed indicators)

Step	Parameter	Unit	Description
37	$(\Delta H/\Delta V)_t$	feet/knots	Figure V 8 in Appendix and steps 20 and 23
38	ΔH_{pc_t}	feet	36 x 37 , Test position error correction (from airspeed indicators)

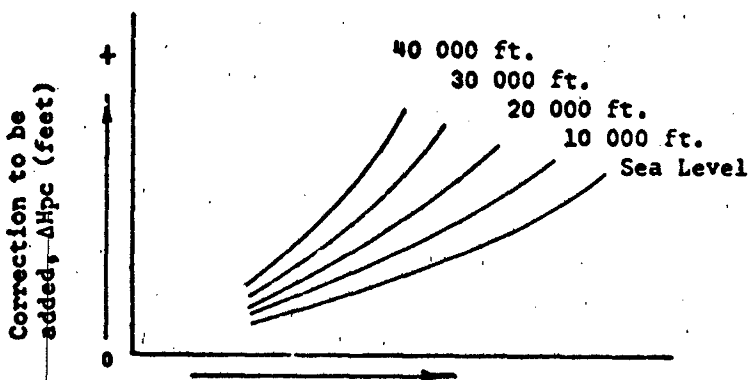
The following additional steps in data reduction are required to obtain the temperature probe recovery factor, K:

Step	Parameter	Unit	Description
39	t_{i_t}	deg C	Indicated ambient free air temperature
40	Δt_{ic_t}	----	Temperature indicator instrument correction
41	t_{ic_t}	deg C	Temperature corrected for instrument error, 39 + 40
42	T_{ic_t}	deg K	41 + 273.16
43	t_{a_t}	deg C	13 and weather balloon soundings
44	T_{a_t}	deg K	43 + 273.16 or T_a from line intercept as shown on figure IV 34
45	(T_{ic}/T_a)	----	42 / 44
46	$(T_{ic}T_a - 1)_t$	----	45 - 1.0
47	M	----	24 + 27
48	M^2	----	47^2
49	$M^2/5$	----	48 / 5
50	K_t	----	Temperature probe recovery factor from slope of line of 46 versus 49. Shown in figure IV 33
51	S	sq ft	Wing area
52	C_L	----	Lift coefficient = $\frac{0.000675 \times 35}{49 \times 51}$



27 V_{ic}, Indicated Airspeed (knots)

Figure IV 27



V_{ic}, Indicated Airspeed (knots)

Figure IV 28

TYPICAL AIRSPEED CALIBRATION FOR NOSE OR WING BOOM INSTALLATION

Figure IV 29

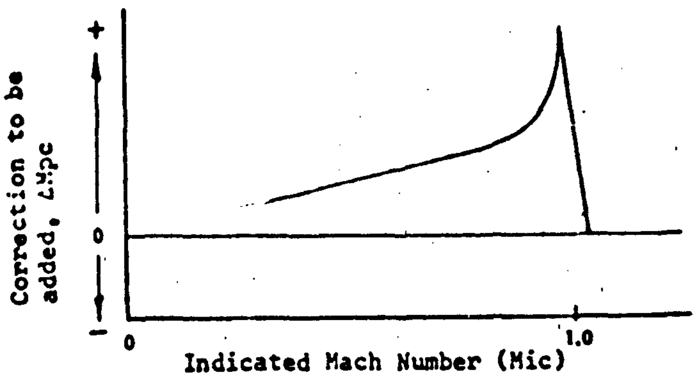


Figure IV 30

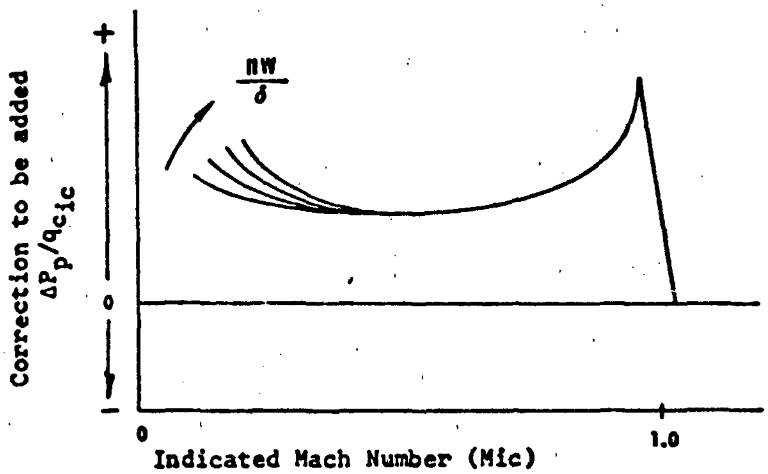
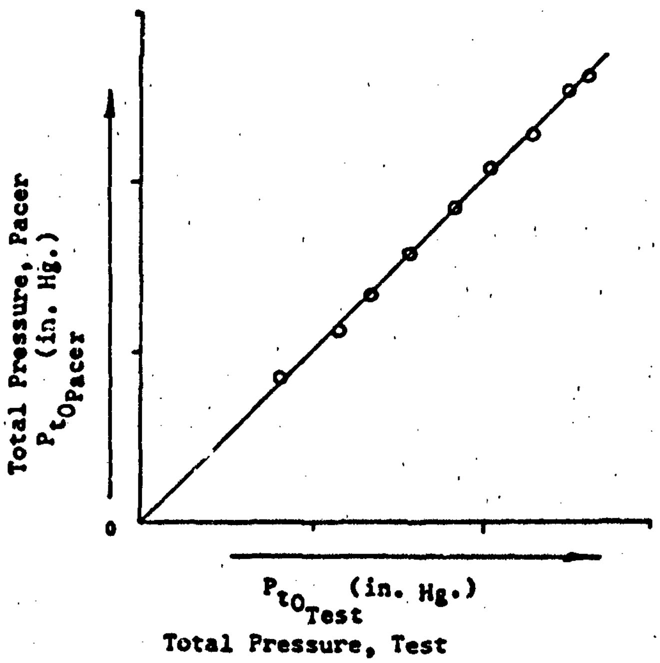


Figure IV 31



TYPICAL CALIBRATION FOR NOSE OR WING BOOM INSTALLATION

4. Smoke Trail Accelerations/Radar Tracking:

Calibration of the pitot-static system in the transonic speed range can be accomplished by the smoke trail acceleration method. The method is similar to the tower fly-by method since a pressure altitude is established by a pacer with the capability to generate a smoke trail at the desired altitude. When available, contrails provide an unlimited trail and can be used instead of the smoke trail. Once the trail has been established, the test airplane accelerates from some distance behind the pacer and approaches the trail so that the desired speed range is covered as the test airplane accelerates alongside the reference trail. The acceleration is continued until the test airplane almost overtakes the pacer, then decelerates through the same airspeed range as used in accomplishing the acceleration. The contrail provides a visual constant altitude reference for the pilot in the test airplane. (The pilot's altitude indication will change as the airplane accelerates and decelerates.) The pacer generating the smoke or contrail should stabilize on the altitude and airspeed with the indicated altitude not varying by more than ±10 feet, during the period the trail is generated. Figure IV 32 is a suggested level acceleration and deceleration mission profile using the pacer to generate the reference smoke or contrail. The ground recording equipment can be either radar or Askania cameras. This test can usually be accomplished during a pace mission after the stabilized pace data are obtained. This is done so the test airplane will be at a lighter gross weight, but with enough fuel remaining to perform one or two accelerations. Photopanel camera recording speed should be set a a frame rate adequate to record the entire run. Correleation counter readings should be obtained on both pacer and test airplane. The test airplane should record data at a high rate to obtain sufficient test data points through the "Mach jump" (transonic) portion of the airspeed calibration.

Airspeed calibrations in the transonic (0.9 to 1.1 Mach) or for the supersonic speeds (above 1.1 Mach) can be accomplished by using either a smoke trail or radar tracking separately or by using both methods at the same time. The method employing radar tracking is preferred at the AFFTC. Usually radar tracking with a smoke trail is used to obtain the calibration; however, the smoke trail method is used if radar tracking is not available.

Airspeed calibrations in the supersonic range using radar tracking can be accomplished with the test airplane with no pacer support, provided an accurate subsonic airspeed position error curve of the test pitot-static system has already been established. This assumes that the supersonic position error is small so that during the acceleration the altimeter indication change will also be small and can be adjusted after review of the radar and airborne recorded data. Regardless of the method used, a pressure altitude survey must be accomplished to convert tapeline altitude to pressure altitude. Pressure altitude data obtained from the test airplane is plotted against tapeline altitude obtained from radar tracking. Test pressure altitude data are usually obtained from the pacer that generated the smoke trail or from the pressure survey conducted with the test airplane prior to accomplishing the acceleration(s) and deceleration(s).

An altitude survey can also be obtained by having the radar station track a weather balloon released a short enough time before to allow enough time for radar to track the balloon to an altitude at which the airspeed calibration accelerations are to be conducted.

Indicated radar track test altitude variations recorded during the accelerations and decelerations are used to make incremental adjustments to the test indicated altitude. This is accomplished by comparing the radar track and the test airplane recorded data at any instant during the acceleration. Data correlation between the airplane instrumentation (for pressure altitude) and radar

tracking (for tapeline altitude) is accomplished by using a side-tone (normally of 1,000 cycles generated and transmitted by the test airplane radio) for instantaneous event marking of the data being recorded by the test airplane and the radar station. The installation and use of a "C-Band" radar beacon on the test airplane facilitates radar tracking.

The pilot's technique for accomplishing this test is described in the ARPS Manual, AFFTC-TN-59-46. The same checklist is used in preparation for this test as used for the pacer method. The following data are recorded:

<u>Pacer Airplane</u>.

1. Correlation number - smoke trail start counter number or event mark and end counter number or event mark.

2. Indicated airspeed (V_i).

3. Indicated altitude (H_i).

4. Free air temperature (t_i).

5. Remarks.

<u>Test Airplane</u>.

1. Correlation counter number.

a. Record counter number or event mark at the beginning and end of the acceleration or deceleration.

2. Remarks

The test airplane airspeed calibration is calculated using 3- to 5-knot airspeed increments throughout the acceleration or deceleration. Each test point is referenced to the pacer pressure altitude. the following is the data reduction outline for the smoke trail acceleration.

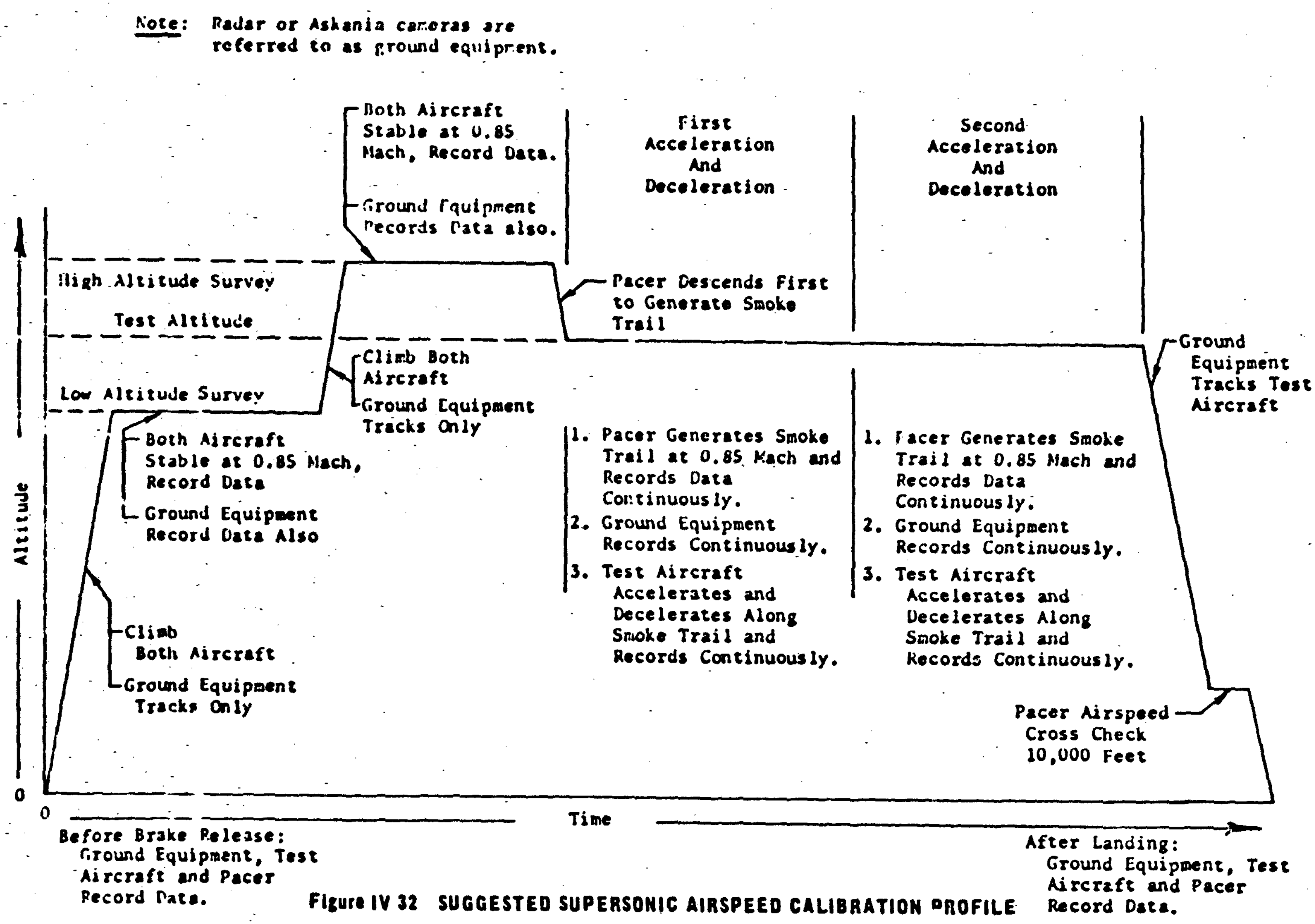


Figure IV 32 SUGGESTED SUPERSONIC AIRSPEED CALIBRATION PROFILE

Smoke Trail Accleration Data Reduction Outline.

Step	Parameter	Unit	Description
1	Point No.	----	
2	Counter No.	----	Correlation
3	V_{i_p}	knots	Indicated airspeed
4	ΔV_{ic_p}	knots	Airspeed indicator instrument correction
5	V_{ic_p}	knots	3 + 4, Airspeed corrected for instrument error
6	H_{i_p}	feet	Indicated altitude
7	ΔH_{ic_p}	feet	Altimeter instrument correction
8	H_{ic_p}	feet	6 + 7, Altitude corrected for instrument error
9	M_{ic_p}	----	From 5 and 8, Mach number Chart 8.5 in reference 1 (AFTR 6273)
10	ΔM_{pc_p}	----	Pacer position error calibration at 9
11	$(\Delta M_{pc}/\Delta H_{pc_p})_p$	10^{-5}/feet	Figure V 9 in Appendix and steps 8 and 9
12	ΔH_{pc_p}	feet	10 / 11, Position correction
13	H_{c_p}	feet	8 + 12, Pressure altitude
14	V_{i_t}	knots	Indicated airspeed
15	ΔV_{ic_t}	knots	Airspeed indicator insturment correction
16	V_{ic_t}	knots	14 + 15, Airspeed corrected for instrument error
17	H_{i_t}	feet	Indicated altitude
18	ΔH_{ic_t}	feet	Altimeter instrument correction

Step	Parameter	Unit	Description
19	H_{ic_t}	feet	17 + 18 , Altitude corrected for instrument error
20	M_{ic_t}	----	From 19 and 16 , Mach number from Mach Chart
21	$(\Delta M_{pc}/\Delta H_{pc})_t$	10^{-5}/feet	Figure V 9 in Appendix and steps 19 and 20
22	ΔH_{pc_t}	feet	13 - 19 , Test position error correction
23	ΔM_{pc_t}	----	21 x 22 , Test position error correction
24	$\{\Delta M_{pc}/(\Delta P_p/q_{c_{ic}})\}_t$	----	Figure V 10 in Appendix and 20
25	$(\Delta P_p/q_{c_{ic}})_t$	----	23 / 24 , Test position error correction

The following smoke trail acceleration data reduction outline employs radar tracking data. Pacer pressure altitude is obtained by steps 1 to 13 and plotted against radar tapeline altitude data to obtain the altitude pressure survey.

Step	Parameter	Unit	Description
26	t_{ref}	sec	Initial event mark reference time
27	$H_{T_{ref}}$	feet	Tapeline altitude from radar track data at time t_{ref}, 26
28	$H_{C_{ref}}$	feet	From pacer pressure altitude survey plot of H_C (pacer) versus H_T (radar) for 27
29	V_i	knots	Indicated airspeed at 26
30	ΔV_{ic}	knots	Airspeed indicator instrument correction
31	V_{ic}	knots	29 + 31 , Indicated airspeed corrected for instrument error
32	H_i	feet	Indicated altitude at 26

Step	Parameter	Unit	Description
33	ΔH_{ic}	feet	Altimeter instrument correction
34	H_{ic}	feet	32 + 33 , Indicated altitude corrected for instrument error
35	ΔH_{pc}	feet	28 - 34 , Position error correction
36	M_{ic}	----	Mach number, 21 and 34 and Chart 8.5 in reference 1 (AFTR 6273)
37	$\Delta M_{pc}/\Delta H_{pc}$	10^{-5}/feet	33 and 34 and figure V 9
38	ΔM_{pc}	----	35 x 37 , Position error correction for initial point
39	t_i	sec	Subsequent time for point after 26
40	H_{T_1}	feet	Tapeline altitude at time t_1, 39
41	$\pm\Delta H$	feet	27 - 40 , Tapeline altitude incremental correction. $\pm\Delta H = H_{T_{ref}} - H_{T_1}$
42	H_{ic_1}	feet	34 + 41 , Corrected indicated altitude at 39
43	ΔH_{pc}	feet	28 - 42 , Position error for subsequent point
44	ΔM_{pc}	----	43 and 37 , 37 is obtained from M_{ic_1} for V_{ic_1} and H_{ic_1}

The following data reduction outline is used when the subsonic portion of the position error curve for the test airplane is known. The acceleration is initiated at a subsonic speed where the position error is known. No smoke trail is used for a visual reference.

Step	Parameter	Unit	Description
45	t	sec	First event mark reference time at subsonic airspeed
46	H_T	feet	Tapeline altitude from radar track data at t, 45

Step	Parameter	Unit	Description
47	V_i	knots	Indicated airspeed at t, 45
48	ΔV_{ic}	knots	Airspeed indicator instrument correction
49	V_{ic}	knots	Indicated airspeed corrected for instrument error
50	H_i	feet	Indicated altitude at 45
51	ΔH_{ic}	feet	Altimeter instrument correction
52	H_{ic}	feet	Indicated altitude corrected for instrument error
53	M_{ic}	----	Mach number, 49 and 52 and Chart 8.5 in reference 1 (AFTR 6273)
54	ΔM_{pc}	----	From subsonic position error curve calibration
55	$\Delta M_{pc}/\Delta H_{pc}$	10^{-5}/feet	53 and 52 and figure V 9
56	ΔH_{pc}	feet	54 / 55 , Position error correction
57	H_c	feet	52 + 56 Pressure altitude
58	Plot: 57 versus 46		

NOTE: Repeat steps 45 to 57 , at subsonic airspeeds and at other event reference times, to obtain other data for the pressure altitude survey ploy of H_C (pressure altitude) versus H_T (tapeline altitude). All the test points for the pressure altitude survey plot (steps 45 to 57) are obtained in a stabilized condition of airspeed and altitude.

Step	Parameter	Unit	Description
59	t_{ref}	sec	Initial event mark reference time at the start of the acceleration
60	$H_{T_{ref}}$	feet	Tapeline altitude from radar track data at time t

Step	Parameter	Unit	Description
61	$H_{c_{ref}}$	feet	From pressure altitude survey plot and 59
62	V_i	knots	Indicated airspeed at 59
63	ΔV_{ic}	knots	Airspeed indicator instrument correction
64	V_{ic}	knots	62 + 63 , Indicated airspeed corrected for instrument error
65	H_i	feet	Indicated airspeed
66	ΔH_{ic}	feet	Altimeter instrument correction
67	H_{ic}	feet	65 + 66 , Indicated altitude corrected for instrument error
68	ΔH_{pc}	feet	61 - 67 , Position error correction
69	M_{ic}	----	Mach number, 64 and 67 and Chart 8.5 in reference 1 (AFTR 6273)
70	$\Delta M_{pc}/\Delta H_{pc}$	10^{-5}/feet	69 and 67 and figure V 9
71	ΔM_{pc}	----	68 x 70 Position error correction
72	t_1	sec	Subsequent time for point after 59
73	H_{T_1}	feet	Tapeline altitude time t_1, 72
74	$\pm\Delta H$	feet	60 - 73 , Tapeline altitude incremental correction. $\pm\Delta H = H_{T_{ref}} - H_{T1}$
75	H_{ic_1}	feet	67 + 74 , Adjusted indicated altitude at 72
76	ΔH_{pc}	feet	61 - 75 , Position error for subsequent point
77	ΔM_{pc}	----	76 and 70 ; 70 is obtained from M_{ic_1} for V_{ic_1} and H_{ic_1}

5. Temperature Probe Recovery Factor:

Every flight test airplane temperature sensing installation requires an accurate calibration to determine the temperature probe recovery factor. The temperature recovery factor (K_t) is normally calculated by using the data obtained when an airspeed calibration is accomplished. The temperature probe recovery factor represents the percent of the total temperature rise detected by the probe. Variation of the recovery factor with variations of Mach number and altitude is not significant for the subsonic speed range. Flight test data from any test where the ambient temperature is known or where the altitude is constant and the airspeed is varied can be used to calculate the recovery factor. The ambient temperature may be obtained from weather balloon soundings or from a pacer temperature system. Calculation of the recovery factor is based on the following equation:

$$\frac{T_{ic}}{T_a} = 1 + K_t \frac{M^2}{5}$$

T_{ic} = Indicated total temperature corrected for instrument error, deg K

T_a = Free air temperature, deg K

M = Free stream Mach number

K_t = Temperature probe recovery factor

Test data (airspeed, altitude and temperature) are generally recorded on the same form as used for the airspeed calibrations by the pacer method (figure IV 23).

The data reduction outline is included in the outline for the reduction of the airspeed calibration by the pacer method (steps 39 through 49).

Figure IV 33 is a typical plot used to obtain a recovery factor. Test results representing various altitudes and the subsonic speed range will plot as one line. The slope of the line is the temperature recovery factor.

Figure IV 34 is another plot used to obtain the K factor. A check of the free air temperature (T_a) for the test altitude is obtained with this plot. Data are plotted for each test altitude and the resulting slope represents the K_t factor. The intercept on the $1/T_{ic}$ scale at zero speed is the ambient free air temperature.

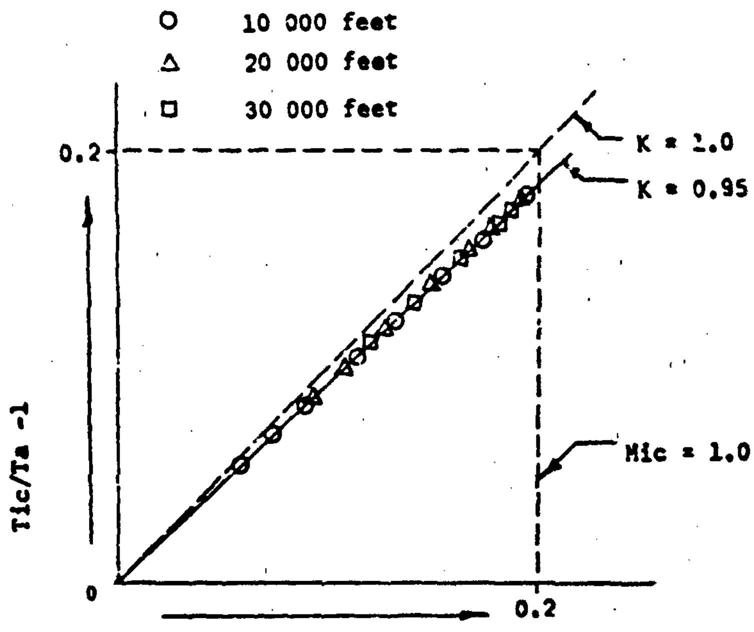


Figure IV 33

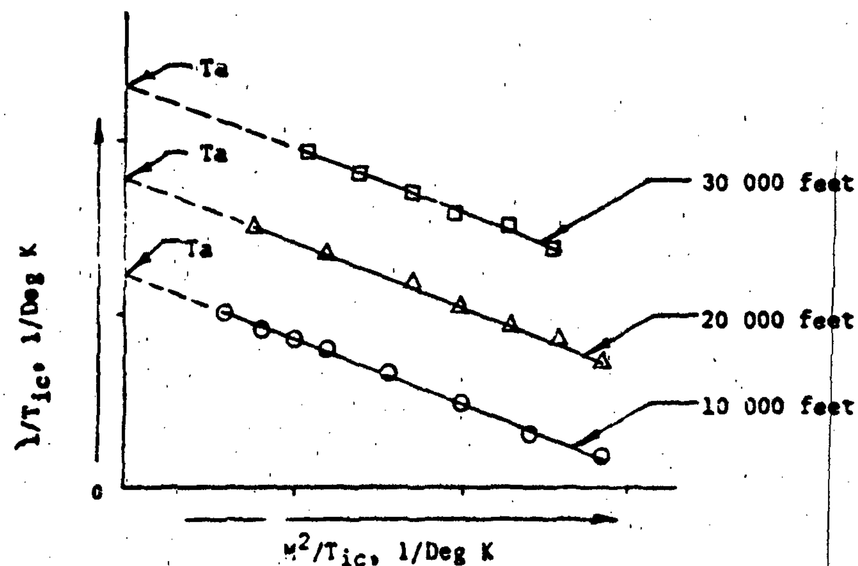


Figure IV 34

TEMPERATURE PROBE RECOVERY FACTOR PLOTS

6. Airspeed Calibration in Ground Effect:

Definition of the position error in ground effect is important in determining airplane performance during the ground roll phase of takeoffs or landings.

The calibration of the airspeed system in ground effect may be otbained from the difference between the altimeter reading prior to brake release and altimeter readings obtained at various speeds during the takeoff ground roll. Test results are plotted in a form of ΔH_{pc} versus indicated airspeed, then a line is faired through the test data which will be representative of the ΔH_{pc} calibration. Values from this faired line, not the test points, are then converted to values of ΔV_{pc} and plotted versus indicated airspeed. It will be noted that the use of this method assumes no total pressure lag during the ground roll, and, as a result, must be applied judiciously.

A ground slope correction must also be applied if a runway slope exists.

Data Reduction Outline for Airspeed Calibration in Ground Effect.

Step	Parameter	Unit	Description
(1)	Counter	----	Sequence
(2)	Time	sec	
(3)	H_i	feet	Indicated altitude prior to brake release
(4)	ΔH_{ic}	feet	Altimeter instrument correction
(5)	H_{ic}	feet	Indicated altitude corrected for instrument error prior to brake release ($H_{ic} = H_c$), (3) + (4)
(6)	H_i	feet	Indicated altitude at each increment read
(7)	ΔH_{ic}	feet	Altimeter instrument correction
(8)	H_{ic}	feet	Indicated altitude corrected for instrument error for each increment read
(9)	V_i	knots	Indicated airpseed at each increment read
(10)	ΔV_{ic}	knots	Airspeed indicator instrument correction
(11)	V_{ic}	knots	Indicated airspeed corrected for instrument error for each increment read; (9) + (10)
(12)	ΔH_{pc}	feet	Position correction in ground effect (5) - (8)
(13)	$\Delta H_{pc}/\Delta V_{pc}$	feet/knot	(8) and (11) and figure V 9 in the Appendix
(14)	ΔV_{pc}	knots	Position correction in ground effect

Determination of Altimeter Lag:

On aircraft that are operationally used for weapons delivery, an evaluation should be conducted to determine the effect of altimeter lag during high rates of descent for the pitot-static system. Altimeter lag can be determined by either the smoke-trail or radar tracking method. Special test instrumentation is not required for either method.

Smoke-Trail Method.

The test technique when using the smoke-trail method consisted of positioning a pacer aircraft at approximately 10,000 feet pressure altitude. The test aircraft is then positioned approximately 5,000 to 10,000 feet above and slightly behind the pacer, such that visual contact is maintained. When both aircraft are in position and the pacer is stabilized on airspeed and altitude, the pacer smoke-generating system is activated. The test aircraft is then put into a dive attitude, a predetermined indicated airspeed and dive angle are established and maintained, and the test aircraft is dived through the reference smoke trail. At the instant the test aircraft passes through the smoke trail, cockpit readings of indicated airpseed, indicated altitude, and dive angle are noted and recorded. The procedure is repeated at varying airspeeds and dive angles to obtain lag data at varying rates of descent. On missions that include dives for lag determination (by either test method), all pitot-static system plumbing that supplies a photo-panel (if the aircraft was so equipped) is disconnected so that the volume of the pitot-static system will closely correspond to that of the operational aircraft.

The calibrated altitude of the smoke trail is calculated from the relationship

$$H_c = H_{ic_{pacer}} + \Delta H_{pc_{pacer}}$$

where

H_c = calibrated pressure altitude (feet)

$H_{ic_{pacer}}$ = indicated pressure altitude corrected for instrument error (pacer aircraft) (feet)

$\Delta H_{pc_{pacer}}$ = correction for altimeter position error (pacer aircraft) (feet)

The altimeter lag during any given dive was computed as follows:

$$\Delta H_{lag} = H_{ic_{test}} - H_c + \Delta H_{pc_{test}} \quad \text{(pitot-static system)}$$

where

ΔH_{lag} = correction for altimeter lag (feet)

$H_{ic_{test}}$ = indicated altitude corrected for instrument error (test aircraft) (feet)

H_c = calibrated pressure altitude (feet)

$\Delta H_{pc_{test}}$ = correction for altimeter position error (test aircraft) (feet)

The rate of descent of the test aircraft as it passed through the smoke trail on any given dive can be calculated as follows:

$$R/D = (101.27)\ \frac{V_{ic_{test}} + \Delta V_{pc_{test}} - \Delta V_{c_{test}}}{\sqrt{\sigma}}\ \sin\gamma$$

where

R/D = rate of descent (feet/minute)

$V_{ic_{test}}$ = indicated airspeed corrected for instrument error (test aircraft) (knots)

$\Delta V_{pc_{test}}$ = correction for airspeed position error (test aircraft) (knots)

$\Delta V_{c_{test}}$ = compressibility correction to calibrated airspeed (test aircraft) (knots)

σ = density ratio

γ = flightpath angle, angle of inclination of the flightpath from the horizontal plane (degrees)

Note:

During lag data analysis, a standard atmospheric temperature profile is assumed.

The flightpath angle is approximated by pitch angle, as read from the production aircraft attitude indicator.

The smoke-trail method has the advantages of providing quick data turnaround time and requiring only the support of a smoke-equipped pacer aircraft. A series of dives for lag determination can be conducted at the end of a scheduled stabilized pace mission. The accuracy of the smoke-trail method is primarily dependent on the pilot's ability to observe and record instantaneous readings of altitude, airspeed, and dive angle as the aircraft passes through the smoke trail at extremely high rates

of descent (rates of descent up to 60,000 feet per minute can be achieved). Although data scatter seldom exceeded ±100 feet, the smoke-trail method is considered rather marginal for precise definition of altimeter lag, due to the inaccuracies inherent in that technique. However, the smoke-trail method provided a quick means of initially determining whether altimeter lag presents a serious problem in a particular aircraft. The method is extensively used for this purpose.

Radar Tracking Method.

In the radar tracking method, as the name implies, the test aircraft performed a series of dives at various rates of descent while being tracked by a ground radar system. When using the radar tracking method, an accurate correlation must be established between tapeline altitude, as measured by the radar, and pressure altitude, as displayed in the aircraft. That correlation is established during these missions by conducting a pressure altitude survey. The test aircraft (assuming that the pitot-static system calibration had previously been accomplished and the position error is known) or a pacer aircraft is flown in stabilized, level, subsonic flight at indicated pressure altitudes of 9,000, 10,000 and 11,000 feet while simultaneously being tracked with radar. By constructing a plot of tapeline altitude versus calibrated pressure altitude, a correlation is established between the two quantities at that particular time. The test aircraft is then climbed to a higher altitude, usually 15,000 to 20,000 feet, and put into a dive attitude and maintained through the 11,000- to 9,000-feet altitude band. At approximately 10,000 feet, a correlation tone is activated, which initiates a trace on the radar tracking data, and the tone is stopped at an indicated altitude of 10,000 feet. At the instant the tone is stopped, the corresponding trace on the radar data is ended. The pilot records values of indicated airspeed and dive angle which existed at the

10,000-foot altitude point. By performing several altitude surveys, spaced throughout the mission, a time-varying correlation between tapeline lag and rate of descent is calculated in the same manner as discussed for the smoke-trail method. Rate of descent can also be graphically obtained directly from the altitude time history plot recorded by radar. Examples of altimeter lag test results are shown in figures IV 35 and IV 36.

The following is the data reduction outline for determining the altimeter lag using radar tracking or a pacer aircraft smoke trail for reference.

Step	Parameter	Unit	Description
1	Point No.	----	
2	Counter No.	----	Correlation
3	Time	hour/min/sec	Time of day
4	V_{i_t}	knots	Indicated airspeed
5	H_{i_t}	feet	Indicated altitude
6	ΔV_{ic_t}	knots	Airspeed indicator instrument correction
7	ΔH_{ic_t}	feet	Altimeter instrument correction
8	V_{ic_t}	knots	4 + 6 Airspeed corrected for instrument error
9	H_{ic_t}	feet	5 + 7 Altitude corrected for instrument error
10	M_{ic_t}	----	From 8 and 9, Mach number Chart 8.5 in reference 1
11	ΔH_{pc_t}	feet	From aircraft pitot-static system position error curve
12	H_{c_t}	feet	9 + 11 Pressure altitude
13	ΔV_{pc_t}	knots	From aircraft pitot-static system position error curve
14	V_{c_t}	knots	8 + 13 Calibrated airspeed
15	γ	deg	Pitch angle - from cockpit attitude indicator
16	ΔV_c	knots	Compressibility correction from figure V in the Appendix
17	V_{e_t}	knots	[8 + 13] - 16, Equivalent airspeed

Step	Parameter	Unit	Description
18	σ	----	Altitude table and 12
19	R/D	feet/min	(101.27)(17 / $\sqrt{18}$) sin γ
	Altimeter Lag Using Radar Tracking.		
20	H_T	feet	Radar tapeline altitude at (3)
21	ΔH_L	feet	Altimeter lag error using radar
	Altimeter Lag Using the Pacer Aircraft Smoke Trail.		
22	H_{i_p}	feet	Indicated altitude
23	V_{i_p}	knots	Indicated airspeed
24	ΔH_{ic_p}	feet	Altimeter instrument correction
25	ΔV_{ic_p}	knots	Airspeed indicator instrument correction
26	V_{ic_p}	knots	23 + 25 Indicated airspeed corrected for instrument error
27	H_{ic_p}	feet	22 + 24 , Indicated altitude corrected for instrument error
28	ΔV_{pc_p}	knots	Pacer pitot-static system position error curve
29	ΔH_{pc_p}	feet	Pacer pitot-static system position error curve
30	V_{c_p}	knots	26 + 28 , Calibrated airspeed
31	H_{c_p}	feet	27 + 29 , Pressure altitude of smoke trail reference
32	ΔH_L	feet	31 - 12 , Altimeter lag using pacer aircraft smoke trail reference

Plot: ΔH_L versus R/D for various dive angles

F-105B USAF S/N 57-5815 AND 57-5804
REC MODEL 856DU COMPENSATED
PITOT-STATIC PROBES
CRUISE CONFIGURATION

SYMBOL	PROBE MODEL	AIRCRAFT
⊙	-1 & 2 (REV. D)	57-5815
△	-3 & 4 (REV. A)	57-5815
⊡	-1 & 2 (REV D)	57-5804
◘	-3 & 4 (REV. A)	57-5804

NOTES:
1. DATA OBTAINED AT 10000 FEET USING RADAR TRACKING.
2. AAU-19/A ALTIMETER IN RESET.
3. DATA REPRESENTS TOTAL ALTIMETER SYSTEM LAG AND INCLUDES MECHANICAL LAG IN THE SYSTEM.

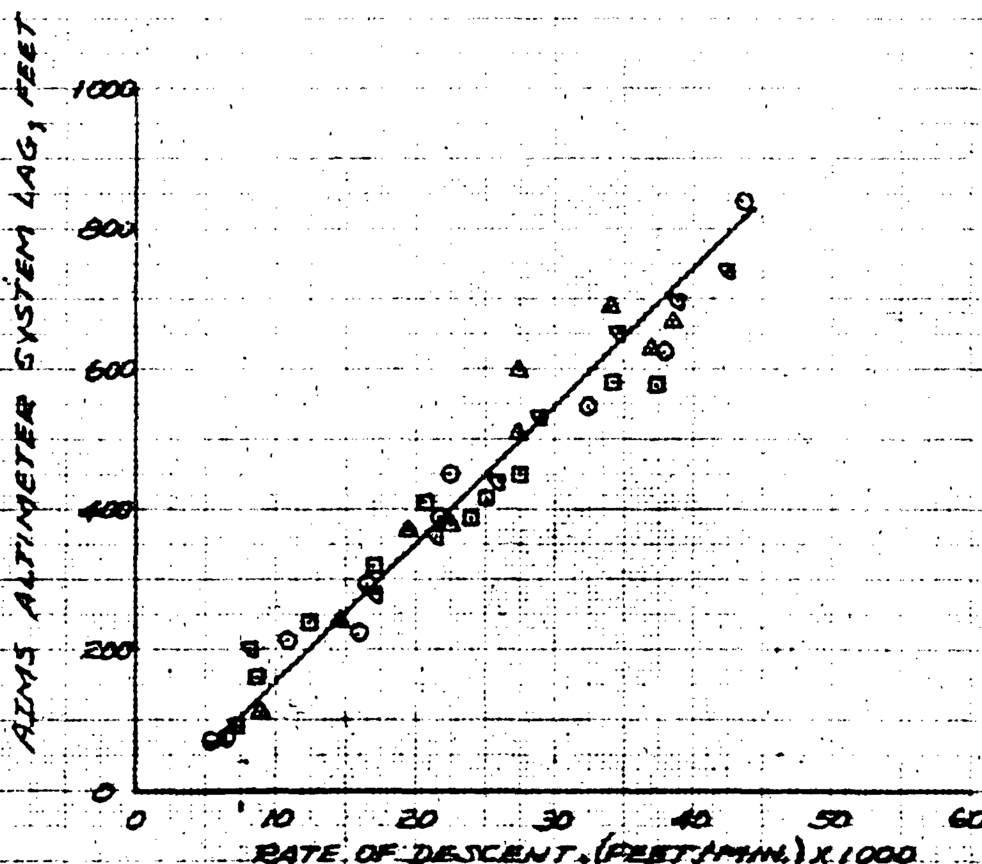


FIGURE IV 35 ALTIMETER SYSTEM LAG

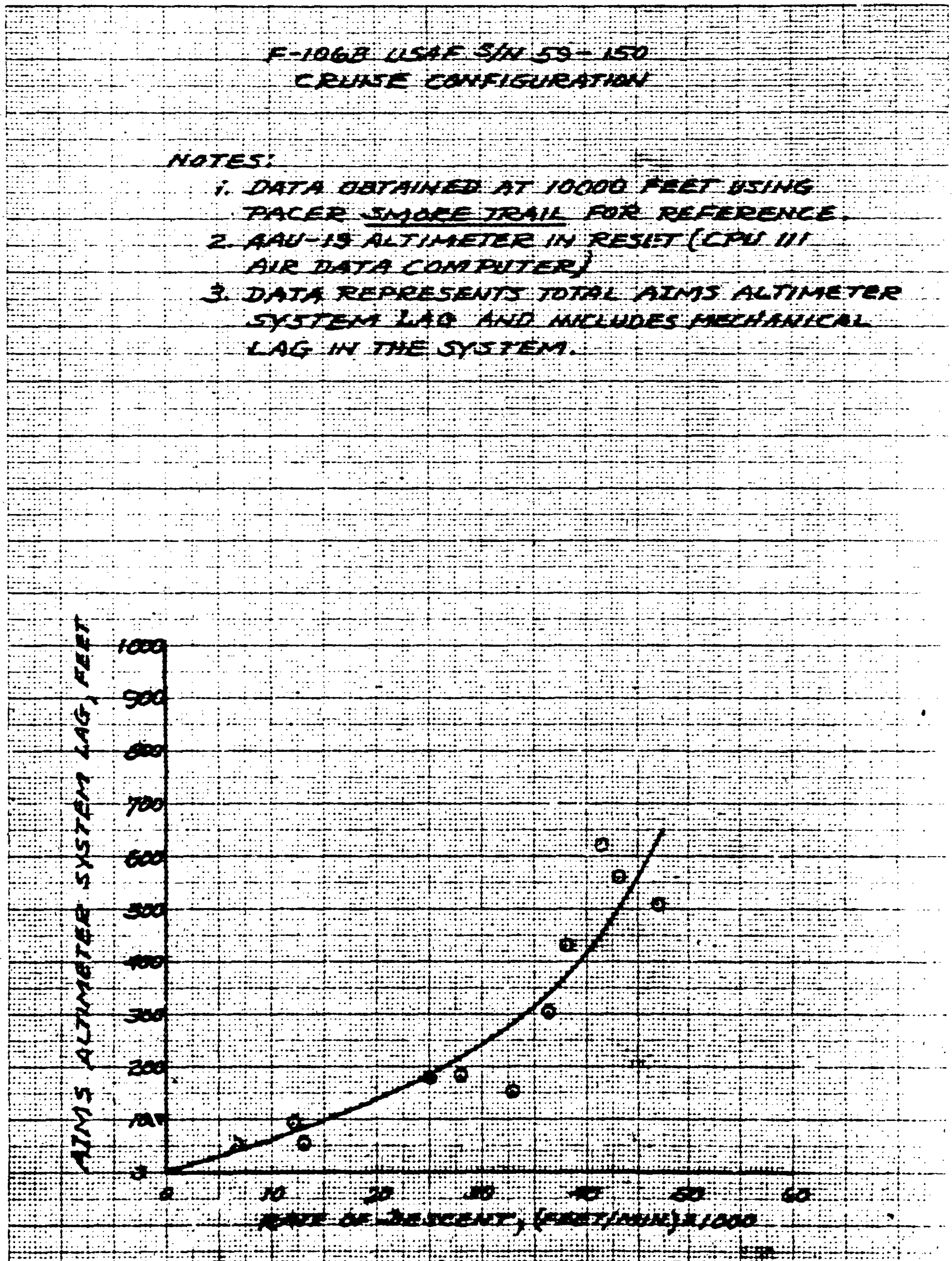


FIGURE IV 36 ALTIMETER SYSTEM LAG

Pitot-Static System End-to-End Check Procedure:

The following material is representative of the use of the TTU 205 pressure-temperature test set in providing an end-to-end check of nonstandard temperature and pitot-static system in test aircraft.

A schematic of the equipment used to accomplish the end-to-end checks of the pitot-static system is shown in figure (1). The instrumentation test equipment required is the following:

1. Ground Power Cart - for aircraft power.

2. TTU 205 B/E - pressure/temperature test set.

3. Kollsman Precision Monitor PPM) transducers (two required to measure P_t and P_s pressures).

4. Decade Box - to simulate total temperature inputs.

5. Thermometer - to measure ambient temperature.

6. Pitot-static Probe Adapters - to connect total and static pressure lines.

7. Tube Fittings and Valves - as required to accomplish plumbing hookup.

The test equipment is connected (as shown in figure IV 37) in the following suggested order:

A. Connecting the total pressure lines:

1. Install the pitot-static probe adapter on the pitot-static probe.

2. Connect the total pressure line to the total pressure fitting on the adapter.

3. Connect T-fitting to the total pressure lines which will be used to connect the Kollsman Pressure Monitor (PPM).

4. Connect another section of line from the T-fitting to the TTY 205 test set total pressure connection.

5. Connect the Kollsman PPM to the T-fitting.

B. Connecting the static pressure lines:

1. The static pressure lines are connected in the same order as the total pressure lines; except that the lines are connected to the static pressure fitting on the pitot-static probe adapter.

Test total and static pressure lines may also be connected to the total and static pressure lines of the aircraft if special T-fittings are provided in the pitot-static system. In that case, the pitot-static probe total and static pressure source ports have to be plugged. A careful check must be made to determine if the pitot-static probe is provided with a water drain hole. The drain hole must also be plugged to preclude a pitot-static system leak.

C. The decade box is connected to the total temperature system. The installed total temperature probe is usually a Rosemount total temperature probe. The temperature probe is disconnected and replaced with the decade box which will be used to simulate the total temperature by varying the resistance.

After the plumbing hookup is completed and the decade box connected, the TTU 205 test set and the Kollsman PPM transducers are connected to the electric power sources. Note that the PPM transducers require 110 VAC, 60 Hz and the TTU 205 test set uses 110 VAC, 400 Hz. Before power is applied, a careful inspection of the plumbing hookup must be accomplished to ensure that the total and static lines are properly connected and that the total and static lines have not been crossed.

Next, both the aircraft power and the test instrumentation power are turned on. The aircraft power is turned on first and allowed to stabilize for a few seconds before the test instrumentation is turned on. The ground equipment TTU 205 test set and PPM transducers are then turned on and allowed to stabilize. The PPM transducer requires at least 15 minutes to warm up before data can be recorded.

If everything is ready and has been checked, the TTU 205 is set to a low airspeed and altitude such as 150 knots and 3,000 feet, and then the airspeed and altitude values are slowly increased to 300 knots and 15,000 feet. An observer familiar with the operation of the test instrumentation will be monitoring the operation in the cockpit of the aircraft. Similarly, the ground equipment will be operated and monitored by a qualified technician. A leak check of the pitot-static system is accomplished at this point. Both the altitude (P_s) and airspeed (P_t) are leak checked. If leakage is found and is greater than the allowed specifications, the leak(s) must be eliminated or reduced to an allowable level before continuing any further with the ground checks.

After all the preliminary checks have been accomplished and the plumbing is free of pneumatic leaks, the ground checks can be performed. Data will be obtained and recorded using the attached forms (figures IV 38, IV 39, IV 40).

The following information must be recorded:

1. Aircraft type

2. Serial number (tail number)

3. Date of test

4. Pitot-static system (production, test, etc.)

5. Pressure transducer serial numbers:

    a. Total pressure (P_t)

    b. Static pressure (P_s)

6. Temperature probe element serial number

7. Central air data computer (CADC) serial number

8. Visual cockpit instruments serial numbers:

    a. Airspeed indicator

    b. Altimeter

The following data will be recorded:

A. Cockpit Data:

1. Test point sequence number

2. Correlation number

3. Airspeed

4. Altitude

5. Mach number

6. Temperature

B. Ground Data:

1. Test point sequence number

2. Airspeed (TTU 205 B/E test set)

3. Altitude (TTU 205 B/E test set)

4. Total pressure (P_t) - PPM transducer

5. Static pressure (P_s) - PPM transducer

6. Decade box setting - Temperature input simulation

The end-to-end check of the recorded data is accomplished by comparing the pitot-static input with the output obtained from the cockpit visual displays, instrument readings, or from the airborne printer. The data pressure values obtained from the PPM transducers are converted to airspeed and altitude as follows:

A. Input P_s in in. Hg is changed to altitude by using the U. S. 1962 standard atmosphere table or calculating altitude from the altitude equation.

P_s = static pressure, in. Hg

P_t = total pressure, in. Hg

V_c = calibrated airspeed, feet

H_c = pressure altitude, feet

$q_c = \Delta P = P_t - P_s$

for $P_s \geq 6.68321$ in. Hg (for below 36089.24 feet)

$$H_c = -1.45442 \times 10^5 \{(\frac{P_s}{29.92126})^{0.190262} - 1\}$$

B. Input P_t in combination with P_s is used to obtain the indicated airspeed from the relation:

Indicated airspeed, $V_{ic} = f(\Delta P)$; $\Delta P = P_t - P_s = q_{c_{ic}}$

The ΔP differential pressure can be converted to indicated airspeed from an impact pressure ($q_{c_{ic}}$) table or calculated using the subsonic aerodynamic equation.

For $V_c = 661.48$ knot, $q_c \leq 26.71757$ in. Hg

$$V_c = 661.48 \{5[(\frac{q_c}{29.92126} + 1)^{2/7} - 1]\}^{1/2} \text{ knots}$$

The input values of airspeed and altitude, corrected for instrument error, will agree with the output values within some acceptable hysteresis or tolerance band. If the aircraft has an onboard computer or CADC where the position error is programmed, the resulting output values will be adjusted for the magnitude of the position error.

Aircraft: ______ **S/N:** ______ **Date:** ______

Pitot-Static Syst. No.: ______

Pressure Transducers:

Syst. No. 1

P_t - S/N: ______

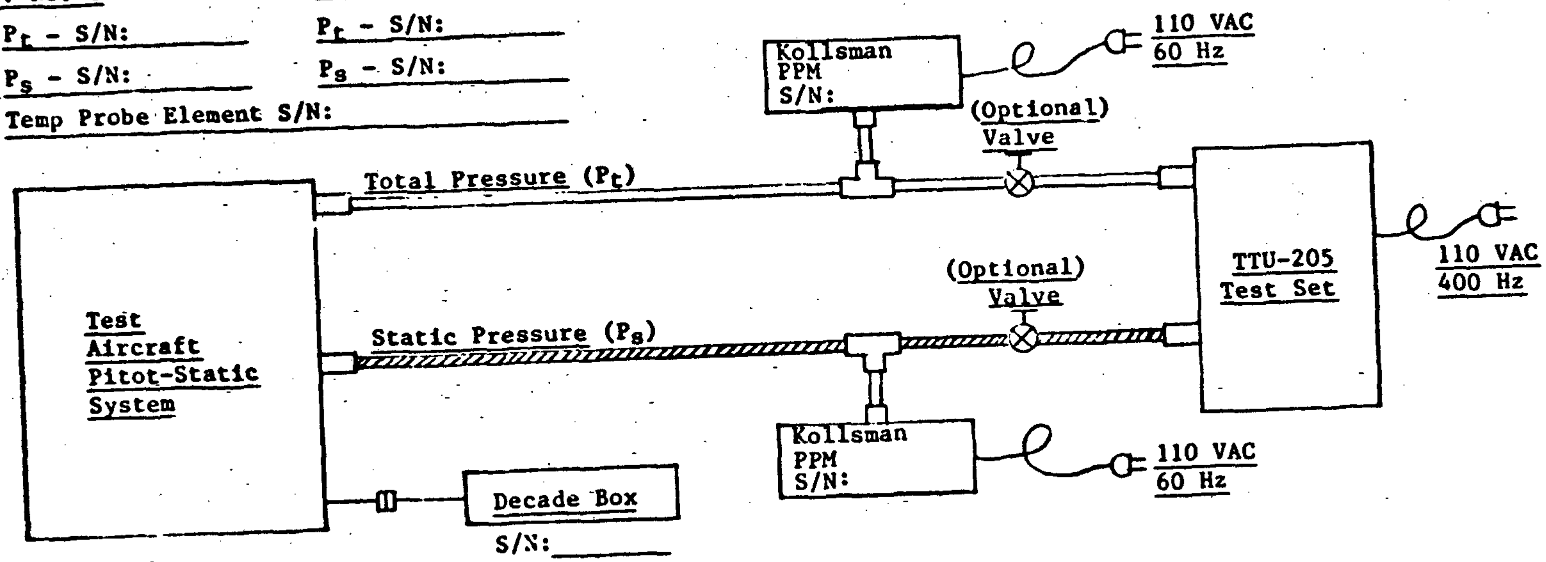
P_s - S/N: ______

Syst. No. 2

P_t - S/N: ______

P_s - S/N: ______

Temp Probe Element S/N: ______



Equipment Required:

1. Ground Power Cart
2. TTU-205 Test Set
3. Kollsman Precision Pressure Monitors (PPM)
4. Decade Box
5. Thermometer
6. Pitot-Static Probe Adapter
7. Tubing Fittings and Valves

Record: Cockpit Data

1. Test Point No.
2. Print No.
3. Airspeed
4. Altitude
5. Mach No.
6. Temperature
7. Obtain Record on Mag. Tape (Optional)

Record: Ground Inputs

1. Test Point No.
2. Airspeed - (TTU-205)
3. Altitude - (TTU-205)
4. PPM-P_t Counts
5. PPM-P_s Counts
6. Decade Box Setting

Figure IV 37 End-To-End Ground Check Requirements

GROUND CALIBRATION CHECKS

Aircraft:__________ S/N:__________ Date:__________

Pitot-Static Syst. No.:__________

Point No.	System Mode	Correl. No.	Cockpit Displays			
			A/S-Kt	Alt-ft	Mach	Temp ^{o}C

Figure IV 38 Cockpit Data Record

GROUNND CALIBRATION CHECKS

Aircraft:__________ S/N:__________ Date:__________

Pitot-Static Syst. No.:__________ Amb. Temp:
at 2,000 ft = +11.0°C
20,000 ft = -24.6°C

Point No.	TTU-205 Alt-ft	TTU-205 A/S-Kt	Mach No.	PPM S/N: Counts	PPM S/N: In. Hg.	PPM S/N: Counts	PPM S/N: In. Hg.	Total Temp °C	Temp Probe OHMS
1	2,000	100	0.158					12.4	52.44
2	2,000	150	0.236					14.2	52.80
3	2,000	200	0.315					16.6	53.26
4	2,000	250	0.393					19.8	53.92
5	2,000	300	0.472					23.7	54.68
6	2,000	350	0.550					28.2	55.57
7	2,000	400	0.628					33.4	56.60
8	2,000	450	0.705					39.2	57.72
9	2,000	500	0.781					45.6	58.99
10	2,000	550	0.878					54.8	60.80
11	2,000	600	0.935					60.7	61.95
1	20,000	150	0.332					-19.1	46.17
2	20,000	200	0.441					-15.1	46.98
3	20,000	250	0.547					-9.7	48.08
4	20,000	300	0.652					-3.5	49.28
5	20,000	350	0.754					+3.6	50.67
6	20,000	400	0.854					+11.6	52.30
7	20,000	450	0.952					+20.0	53.93

Figure IV 39 Ground Data Record

GROUND CALIBRATION CHECKS

Aircraft:__________ S/N:__________ Date:__________

Pitot-Static Syst. No.:__________

Amb. Temp:
at 30,000 ft = $-44.5^{o}C$
at 40,000 ft = $-56.5^{o}C$

Point No.	TTU-205		Mach No.	PPM S/N:		PPM S/N:		Total Temp ^{o}C	Temp Probe OHMS
	Alt - ft	A/S-Kt		Counts	In. Hg.	Counts	In. Hg.		
1	30,000	360	0.932					-4.7	49.06
2	30,000	330	0.862					-10.5	47.88
3	30,000	300	0.791					-15.8	46.82
4	30,000	270	0.718					-20.8	45.84
5	30,000	240	0.643					-25.5	44.91
6	30,000	210	0.567					-29.7	44.10
7	30,000	180	0.489					-33.5	43.32
1	40,000	290	0.938					-18.4	46.30
2	40,000	260	0.853					-25.0	4[illegible].01
3	40,000	230	0.764					-31.2	43.80
4	40,000	200	0.672					-36.9	42.63
5	40,000	180	0.610					-40.4	41.93

Figure IV 40 Ground Data Record

REFERENCES

1. AF Technical Report No. 6273, Flight Test Engineering Handbook, May 1951, Corrected and Revised June 1964.

2. AFFTC-TN-59-46, 1959, Pilot's Handbook for Performance Flight Testing.

3. Brombacher, W. G., Altitude-Pressure Tables Based on the United States Standard Atmosphere, NACA TR No. 538, 1935, Reprinted 1948.

4. International Civil Aviation Organization and Langley Aeronautical Laboratory, Standard Atmosphere - Tables and Data for Altitudes to 65,800 feet, NACA Report 1235, U. S. Government Printing Office, 1955.

5. AFFTC Regulation 55-15, dated 21 December 1976.

6. AFFTC Regulation 55-2, 1 February 1980

7. F-104A and F-104B USAF Series Aircraft Manual T.O. 1F-104A-1, 31 October 1964, Changed 1965.

8. Flight Calibration of Aircraft Static Pressure Systems SRDS Report No, RD-66-3, dated February 1966.

APPENDIX I

The following information and data reduction aid curves are presented for use in the suggested airspeed calibrations data reduction outlines.

INFORMATION

1. Tower Fly-Bys Regulations (AFFTCR 55-2)

2. Operation of Polaroid Camera

LIST OF APPLICABLE CURVES

Figure	Title
V 5	Compressibility Correction to Calibrated Airspeed
V 6	$\Delta M_{pc}/\Delta V_{pc}$ Versus Indicated Mach Number
V 7	ΔV_{pc} Versus Indicated Airspeed for Values of $\Delta P_p/q_{c_{ic}}$
V 8	$\Delta H_{pc}/\Delta V_{pc}$ Versus Indicated Airspeed
V 9	$\Delta M_{pc}/\Delta H_{pc}$ Versus Indicated Mach Number
V 10	$\Delta M_{pc}/\Delta P_p/q_{c_{ic}}$ Versus Indicated Mach Number
V 11	Standard Altitude Table
V 12	Conversion Chart
V 13	Psychometric Chart
V 14A-14M	Airspeed/Mach Number Conversion

12-19. TOWER FLYBY LINE:

a. Description. The tower flyby line (Figure 12-18) is a subsonic airspeed calibration facility which runs parallel to the extended centerline of runway 04/22 approximately midway between the ramp and runway, starting at the northern edge of Rogers Dry Lake and terminating approximately at the west taxiway. Pattern alignment markers are located on the lake bed between the flyby tower and the eastern edge of Rogers Dry Lake. Missions will be conducted VFR during daylight hours only.

*b. Pattern. The standard tower flyby pattern is approximately four NM wide and eight NM long. Variable short patterns, commensurate with mission requirements, may be flown in the shaded area. The downwind leg may be extended a maximum of three NM to accommodate speeds in excess of 400 knots true airspeed (KTAS). When extending the downwind leg, maintain the standard rectangular pattern and ensure that the turn to final is made abeam of the VORTAC. No deviations will be made from the downwind altitude of 3,500 feet MSL. The flyby pattern is east to west, right turns only, and at speeds of less than Mach 1 True. The crosshatched area is an optional short turnout between main base and the housing area for low performance (reciprocating) aircraft only. High performance aircraft will go outside the housing area. Turnout east of housing area (short turnout) will not be made if aircraft are carrying external stores other than fuel tanks or if the drop zone is active. Turn to downwind will be extended toward the northwest approximately two additional miles when the DZ is active.

c. Procedures:

(1) Pilot will:

(a) Contact Edwards Tower for clearance prior to entering flyby pattern.

(b) Maintain communications with Edwards Tower during flyby operations (318.1 primary) and make radio calls per Figure 12-18. Advise Tower when short turnout is to be made or when downwind leg is to be extended.

(c) Abort flyby missions when communication with Edwards Tower is lost.

(d) Maintain separation from other aircraft in the Tower flyby pattern.

(e) Advise Edwards Tower on downwind leg of last pattern and intentions thereafter.

(2) Edwards Tower will:

(a) Grant flyby line clearance.

(b) When the drop zone is active advise all aircraft utilizing the tower flyby line that the drop zone one mile north of the housing area is active, surface to appropriate MSL; live jumps are in progress. All aircraft avoid the area by two NM.

POLAROID CAMERA OPERATING INSTRUCTIONS

1. General:

This camera system has been designed and built especially for recording aircraft fly-by data. Study both the instructions provided herein for making lens settings and the POLAROID FILM HOLDER instructions, posted in the Fly-By Tower, before attempting to load and/or use the camera.

2. Lens Settings:

To obtain an image of both the wire grid (approximately 4 feet from the camera) and the test aircraft (approximately 1,400 feet from the camera) maximum depth of field is required. This is obtained by using a very small lens opening (high aperture number). To obtain a high aperture number of f:90 this lens has been fitted with a "pin-hole" diaphragm which will provide sharp focus from approximately 24 inches to infinity. Use of the pin hole diaphragm requires the lens aperture to be set at f:4.5. The lens aperture setting lever is shown in figure V 2. Recheck that this setting is at f:4.5 (maximum clockwise position when facing lens).

3. Exposure Time:

With the aperture fixed at f:90, as described above, there is only one adjustment that is made to compensate for changing light conditions. Shutter opening time is set by rotating the annular ring as shown in figure V 3 and aligning the desired time with the index. This ring should never be turned to the "B" or "O" position. If this occurs, disassembly of the lens may be required.

Determination of exposure time is made using a photographic exposure meter set for an ASA film speed of 3200 and reading the

exposure time to be used with an aperture of f:90 for the existing light. The computation as read on the meter is the setting used and set as described in the preceding paragraph. Usually a trial photograph is taken before the fly-bys are started to check if the camera is functioning properly and to determine if the exposure time (shutter speed) is approximately correct since an exposure meter is not always available. The usual exposure time is 1/125 of a second.

4. Shutter Operation:

The GRAFLEX OPTAR lens installed on the camera must be "cocked" or wound prior to each exposure. This is accomplished by grasping the sunshade as shown in figure V 1 and gently rotating the sunshade approximately 120 degrees in a clockwise direction. The shutter opening lever (small lever at lower left of lens mount) should always be in the down or "C" (closed) position.

Cocking of the shutter should be the last function performed before taking a picture. The shutter is tripped by use of a flexible shutter release cable. This technique should always be used to avoid imparting any motion or vibration to the camera.

Figure V 1

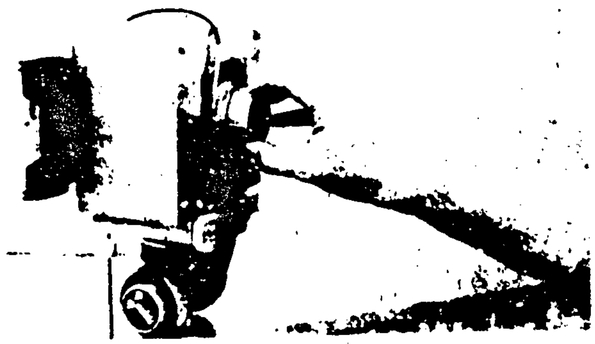


Figure V 2

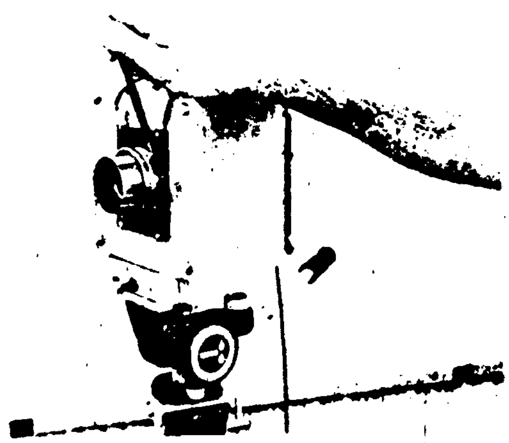
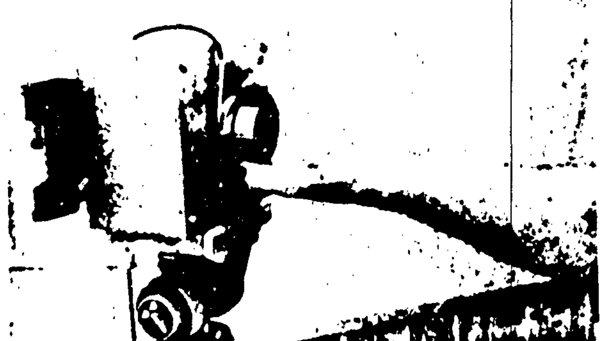


Figure V 3



TOWER FLY-BYS POLAROID CAMERA

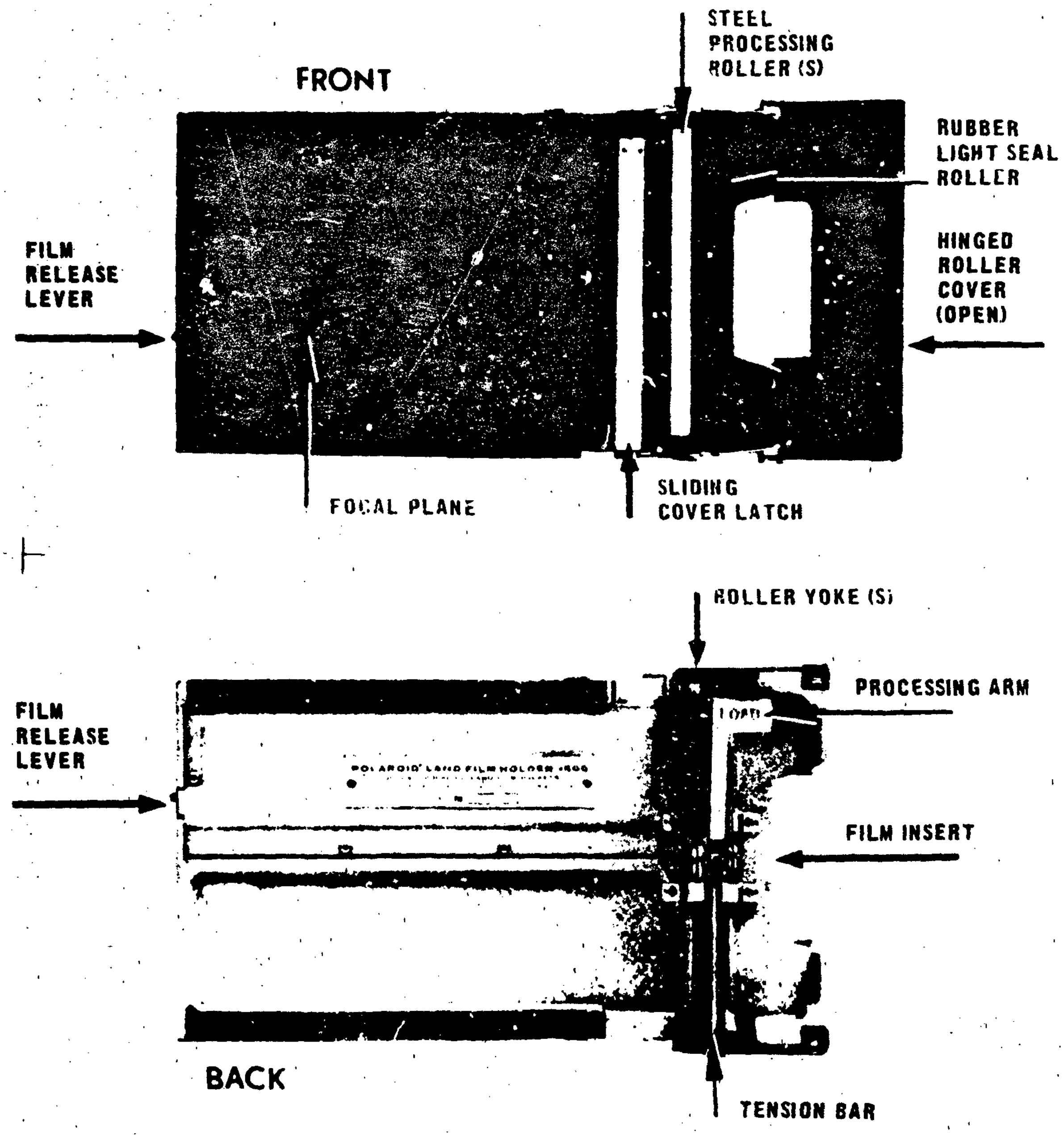


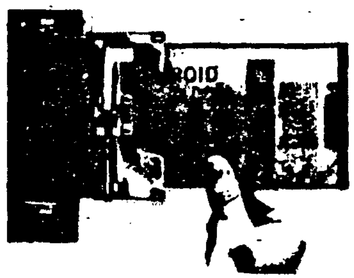
Figure V-4 POLAROID CAMERA FILM HOLDER

POLAROID CAMERA FILM LOADING INSTRUCTIONS

LOADING

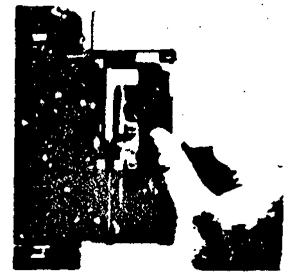
1. Swing the processing arm of the film holder up to the "Load" position.

2. There are two sides to the film packet — right and wrong. Make sure that the side with the large printed letters is facing you. Holding the packet as shown, insert the end with the metal clip into the holder. Push the clip past the rubber light seal roller and, without buckling, feed the packet in about half-way.



3. Now shift your hold to the extreme right-hand edge and push the packet in the rest of the way, until it stops. Use care to avoid buckling or creasing, and do not press on the area where the pod of developing chemicals is located.

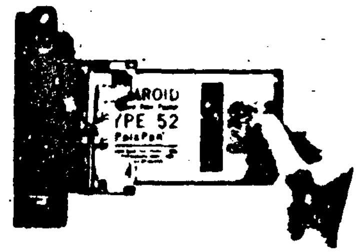
When completely inserted, the right edge of the packet will just be visible in the holder recess (see illustration).



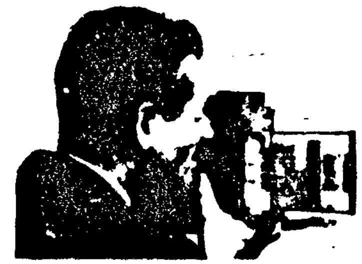
TAKING THE PICTURE

1. The outer envelope acts as a protective cover ("dark slide") for the film. Just before you take the picture, gently withdraw the envelope from the holder until it comes to a firm stop. Don't worry about pulling too far. It will come out almost 6 inches, then stop automatically. The negative will remain inside the holder — uncovered and ready for exposure.

Note: To avoid the danger of a light leak, the protective envelope should not be removed for longer than absolutely necessary. Guard it especially against bending or whipping in the wind.

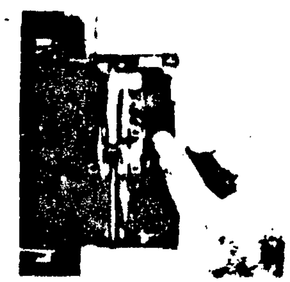


2. Make the exposure just as you would for conventional films. (The speed rating is printed on the film packet, and further instructions are contained in the film box.)

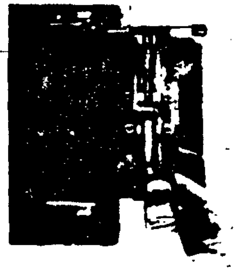


3. After exposure reinsert the envelope, all the way, until it is once more just visible in the holder recess. Use light pressure but don't force it; otherwise you may crease the paper. If the envelope will not slide in easily all the way, withdraw it slightly and try again.

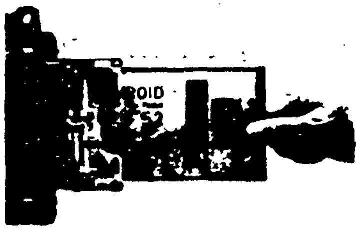
The picture you have just taken is now ready for processing.



PROCESSING



1. Flip the processing arm down to the "PROCESS" position. This action brings together the two steel rollers inside the film holder. When you pull the packet out, these rollers will crush the pod and *spread the developing chemicals.*

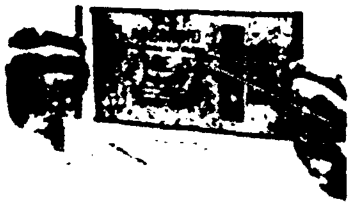


2. To start development, pull the packet completely out of the holder in one smooth, fairly rapid motion. You will feel a slight resistance toward the end as the metal clip reaches the rollers, but keep right on pulling without hesitating. The rollers will separate automatically to allow the clip to pass through.

Remember: pull evenly, steadily, rapidly. Do not place your free hand on the holder as you pull or you may damage your print.

3. Wait the recommended development time. (See directions packed with film.)

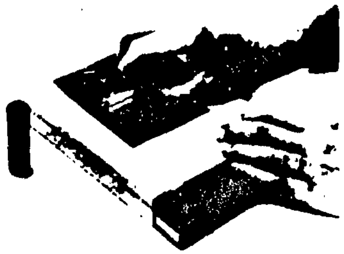
REMOVING THE PICTURE



1. When development is complete, remove the black outer envelope from the packet. Grasp it at the two extreme ends, hooking your fingernails under the edge *of the metal clip. Then give the envelope* a moderate tug. The metal clip will remain attached to the inside sheets; the envelope will slip off (see illustration). **Do not bend, squeeze or pry the metal clip — you will only have more difficulty in removing the envelope.**

2. Now separate the inside sheets. Take the black negative tab and brown paper mask in one hand, the glossy white sheet in the other. Then peel off your finished print quickly, without letting it fall back on the negative.

COATING

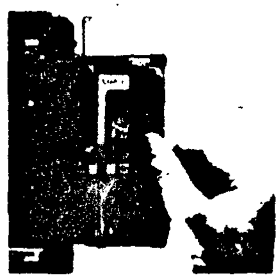


Each black and white picture should be coated with a Polaroid Print Coater as soon as possible after removal from the packet. Use a clean, flat surface such as the film box. Apply the coater liberally *along the entire length of the picture with* 6-8 firm, overlapping strokes. Make sure to cover all edges, borders and corners.

One coater contains sufficient fluid for four pictures. If it should begin to drag or feel dry at any time, press it down hard *for a moment on the tab end of the print* (not on the image) to release more liquid. *Then continue coating evenly across the* picture. Keep the coater tightly capped in the plastic vial when not in use to prevent evaporation of the fluid.

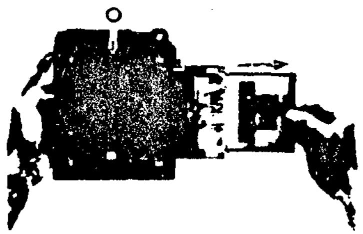
After coating, allow the print to dry thoroughly. This normally will take only a **few** minutes (slightly longer in humid weather). Once coated and dried in this manner, your picture is extremely durable and can be expected to withstand storage as well as conventional photographic images. **Never coat color pictures.**

LATER DEVELOPMENT



Occasionally you may wish to take several pictures in succession without processing each one right away. To remove a packet for later development, follow these steps.

1. Expose the negative and reinsert the protective envelope as usual. Leave the processing arm of the film holder up in the "LOAD" position.



2. Using your thumbnail as shown, depress the film release lever on the left side of the holder (arrow). Push it down as far as it will go (about ⅜") and hold it there. Now briskly withdraw the entire packet from the holder. **Do not let go of the release lever until the packet is completely out.**

COMPRESSIBILITY CORRECTION TO CALIBRATED AIRSPEED

Source: F-104A Flight Manual
T.O. 1F-104A-1

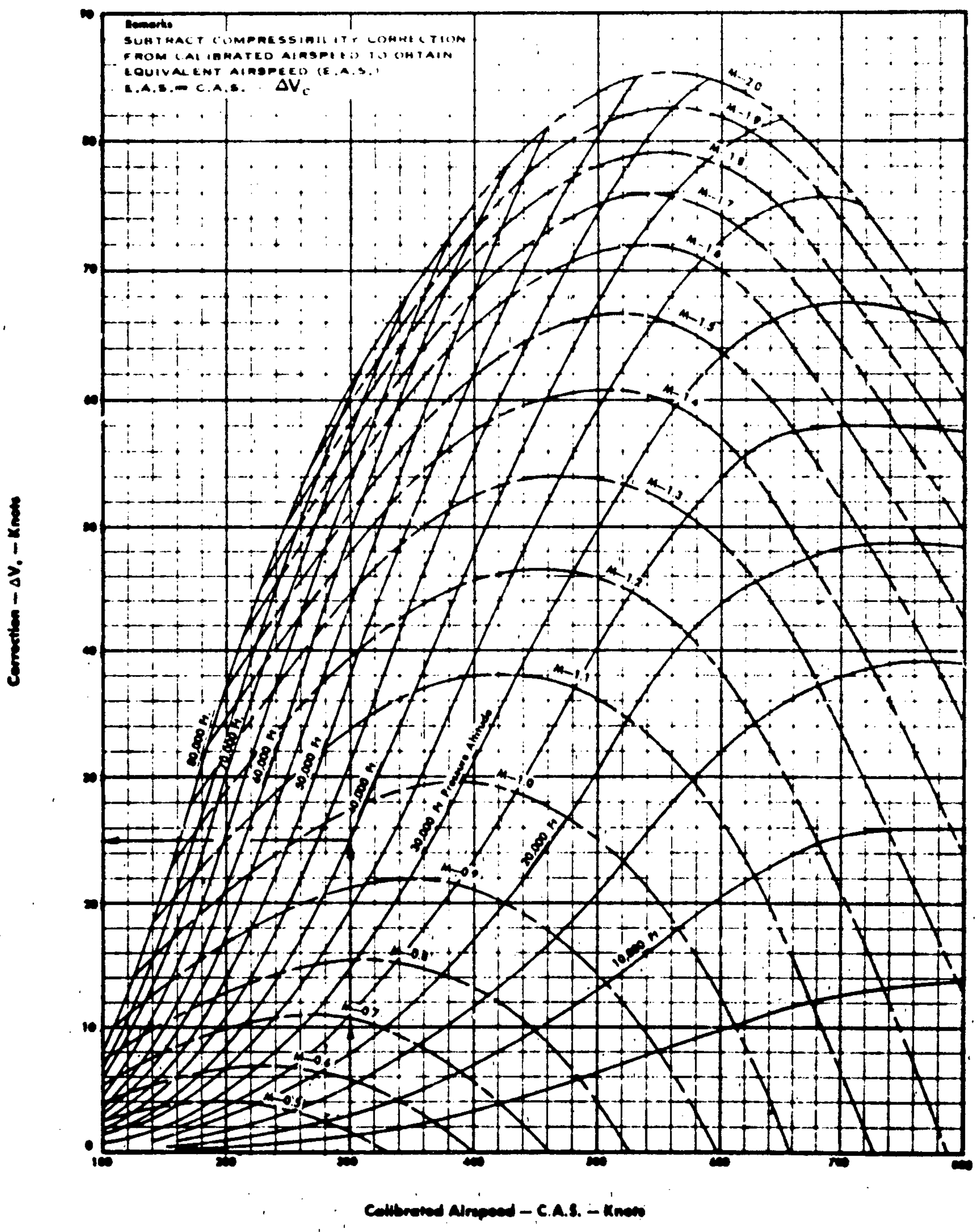


Figure V 5 COMPRESSIBILITY CORRECTION TO CALIBRATED AIRSPEED

RATIO OF MACH METER TO AIRSPEED INDICATOR POSITION ERROR CORRECTIONS, $\Delta M_{pc}/\Delta V_{pc}$ (1/knots) versus INDICATED MACH NUMBER CORRECTED FOR INSTRUMENT ERROR, M_{ic} for INDICATED PRESSURE ALTITUDE CORRECTED FOR INSTRUMENT ERROR, H_{ic} (feet) = CONSTANT

$$\frac{\Delta M_{pc}}{\Delta V_{pc}} = \frac{P_{a_{SL}}}{a_{SL}} \frac{1}{P_s} \frac{V_{ic}}{a_{SL}} \left[1 + 0.2 \left(\frac{V_{ic}}{a_{SL}}\right)^2\right]^{2.5} \frac{(1 = 0.2\, M_{ic}^{2})}{M_{ic}} \qquad V_{ic} \le a_{SL},\ M_{ic} \le 1.00$$

$$\frac{\Delta M_{pc}}{\Delta V_{pc}} = \frac{P_{a_{SL}}}{5a_{SL}} \frac{1}{P_s} \frac{V_{ic}}{a_{SL}} \left[1 + 0.2 \left(\frac{V_{ic}}{a_{SL}}\right)^2\right]^{2.5} \frac{M_{ic}(7M_{ic}^{2} - 1)}{(2M_{ic}^{2} - 1)} \qquad V_{ic} \le a_{SL},\ M_{ic} \ge 1.00$$

$$\frac{\Delta M_{pc}}{\Delta V_{pc}} = \frac{166.921\, P_{a_{SL}}}{a_{SL}} \frac{1}{P_s} \frac{\left(\frac{V_{ic}}{a_{SL}}\right)^6 \left[2\left(\frac{V_{ic}}{a_{SL}}\right)^2 - 1\right]}{\left[7\left(\frac{V_{ic}}{a_{SL}}\right)^2 - 1\right]^{3.5}} \frac{M_{ic}\ (7M_{ic}^{2}-1)}{(2M_{ic}^{2} - 1)} \qquad V_{ic} \ge a_{SL},\ M_{ic} \ge a_{SL}$$

where $P_{a_{SL}} = 29.92126$ in. Hg; $a_{SL} = 661.48$ knots and P_s is measured at H_{ic}.

Note: This curve is valid for small errors only, (say $\Delta V_{pc} < 10$ knots or $\Delta M_{pc} < 0.04$) and should not be used when the position error is larger.

Figure V 6 $\Delta M_{pc}/\Delta V_{pc}$ vs Indicated Mach Number

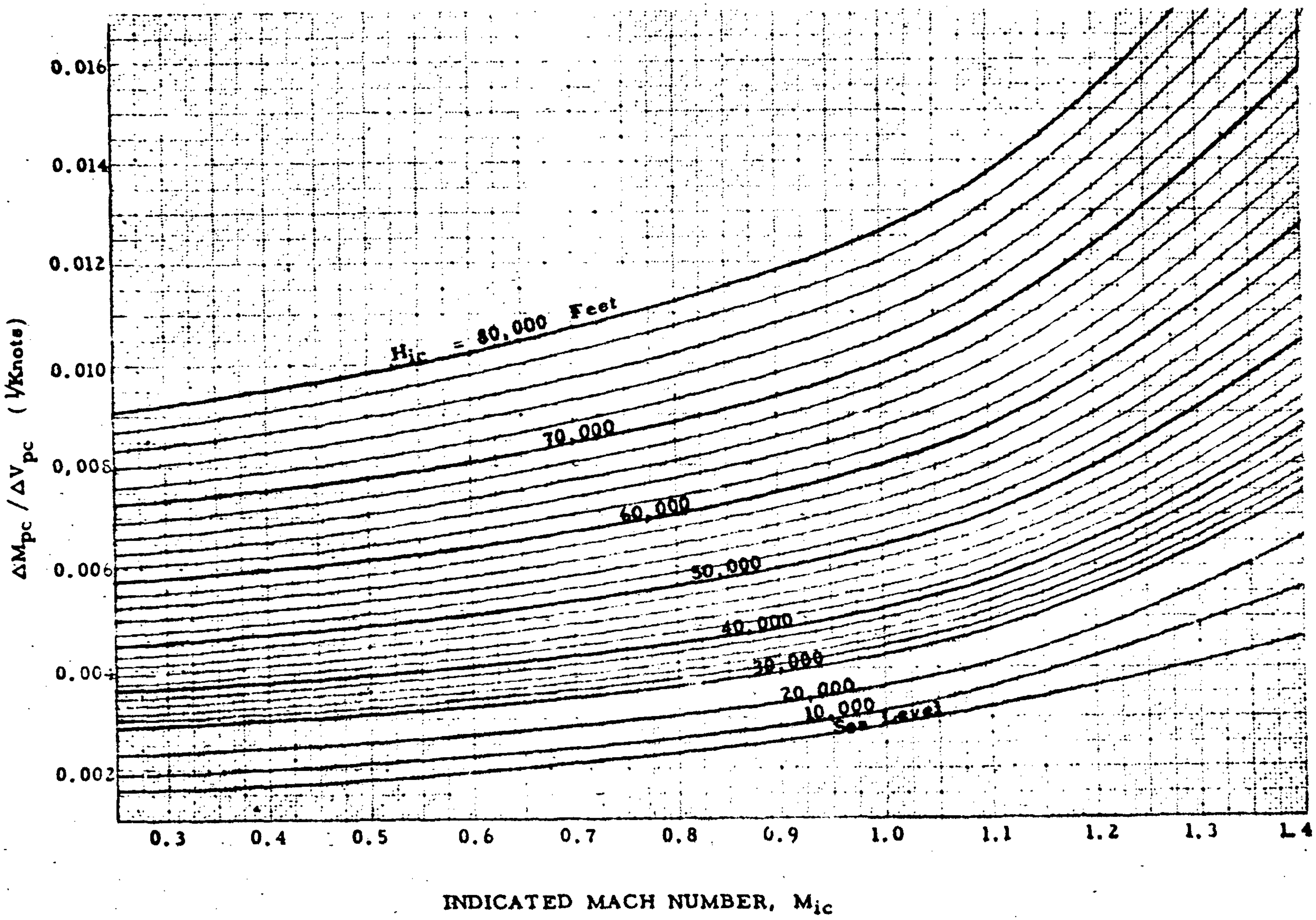


Figure V 6 (CONTINUED)

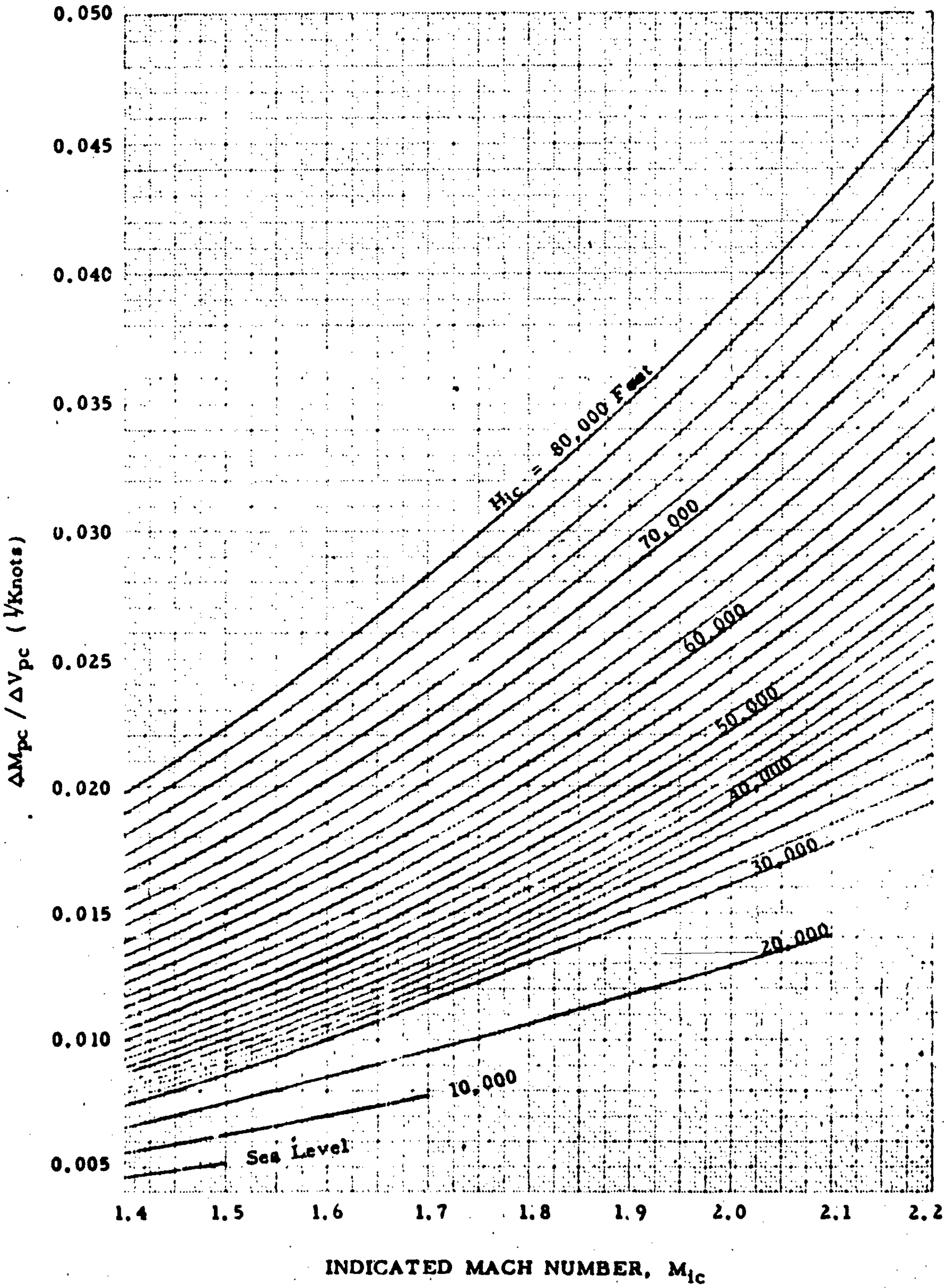


Figure V 6 (CONCLUDED)

AIRSPEED POSITION ERROR CORRECTION, ΔV_{pc} (knots) versus INDICATED AIRSPEED CORRECTED FOR INSTRUMENT ERROR, V_{ic} (knots) for POSITION ERROR PRESSURE COEFFICIENT, $\Delta P_p/q_{cic}$

For $V_{ic} \leq a_{SL}$,

$$\frac{\Delta P_p}{q_{cic}} = \frac{1.4\left(\frac{V_{ic}}{a_{SL}}\right)\left[1+0.2\left(\frac{V_{ic}}{a_{SL}}\right)^2\right]^{2.5}\frac{\Delta P_{pc}}{a_{SL}} + 0.7\left[1+0.2\left(\frac{V_{ic}}{a_{SL}}\right)^2\right]^{1.5}\left[1+1.2\left(\frac{V_{ic}}{a_{SL}}\right)^2\right]\left(\frac{\Delta V_{pc}}{a_{SL}}\right)^2}{\left[1+0.2\left(\frac{V_{ic}}{a_{SL}}\right)^2\right]^{3.5} - 1}$$

For $V_{ic} \geq a_{SL}$,

$$\frac{\Delta P_p}{q_{cic}} = \frac{7\left(\frac{V_{ic}}{a_{SL}}\right)\frac{\left[2\left(\frac{V_{ic}}{a_{SL}}\right)^2 - 1\right]}{\left[7\left(\frac{V_{ic}}{a_{SL}}\right)^2 - 1\right]}\frac{\Delta V_{pc}}{a_{SL}} + 7\,\frac{\left[7\left(\frac{V_{ic}}{a_{SL}}\right)^4 - 4.5\left(\frac{V_{ic}}{a_{SL}}\right)^2 + 3\right]}{\left[7\left(\frac{V_{ic}}{a_{SL}}\right)^2 - 1\right]^2}\left(\frac{\Delta V_{pc}}{a_{SL}}\right)^2}{\left(\frac{V_{ic}}{a_{SL}}\right)^2\left[1 - \frac{\left[7\left(\frac{V_{ic}}{a_{SL}}\right)^2 - 1\right]^{2.5}}{166.921\left(\frac{V_{ic}}{a_{SL}}\right)^7}\right]}$$

where a_{SL} = 661.48 knots

Example:

Given: V_{ic} = 700 knots; ΔV_{pc} = -20 knots

Required: $\Delta P_p/q_{cic}$

Solution: Use figure V 7 (concl.) **For the given conditions,**

$\Delta P_p/q_{cic}$ = - 0.070

Figure V 7 ΔV_{pc} **vs Indicated Airspeed For Values of** $\Delta P_p/q_{cic}$

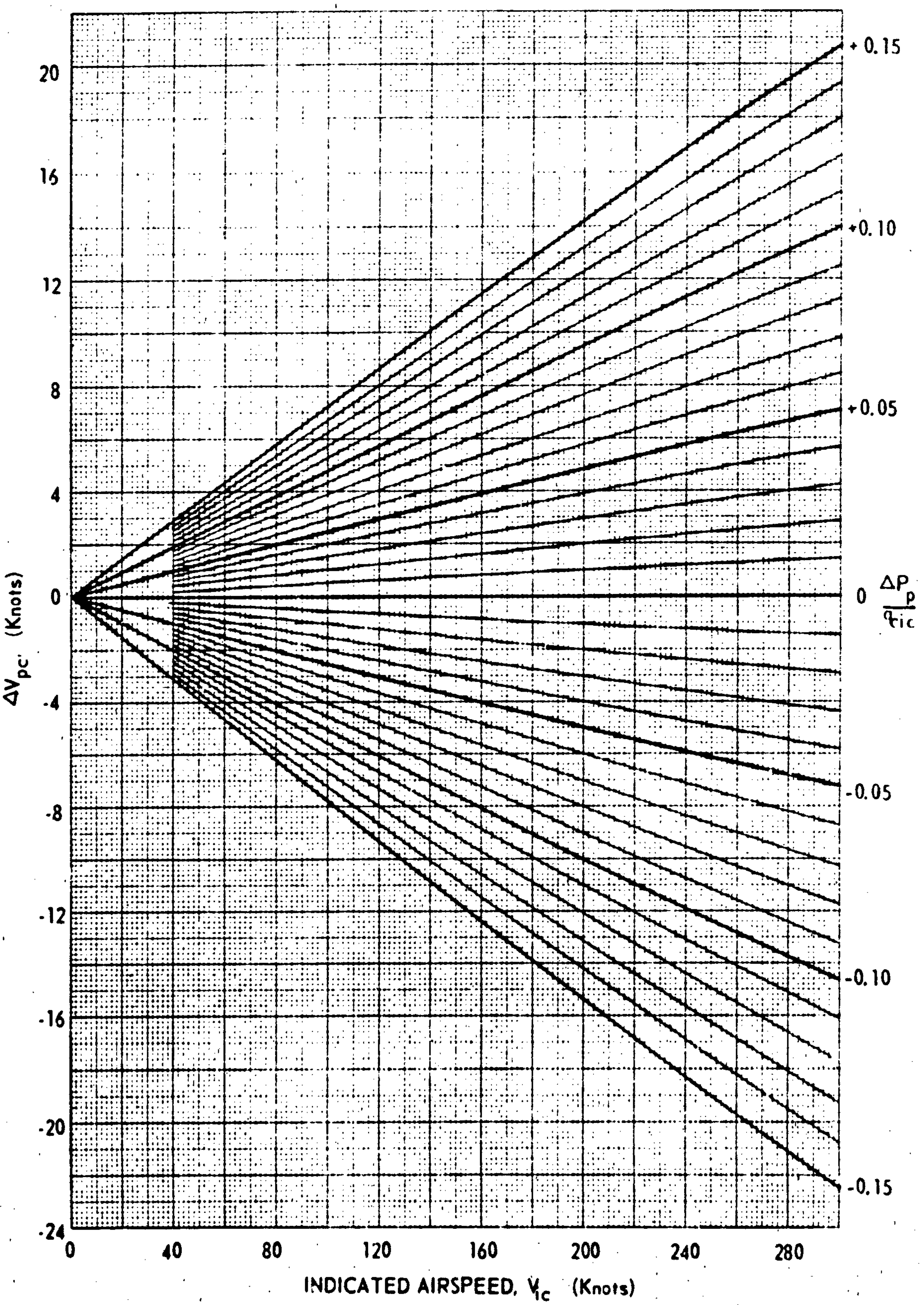


Figure V 7 (CONTINUED)

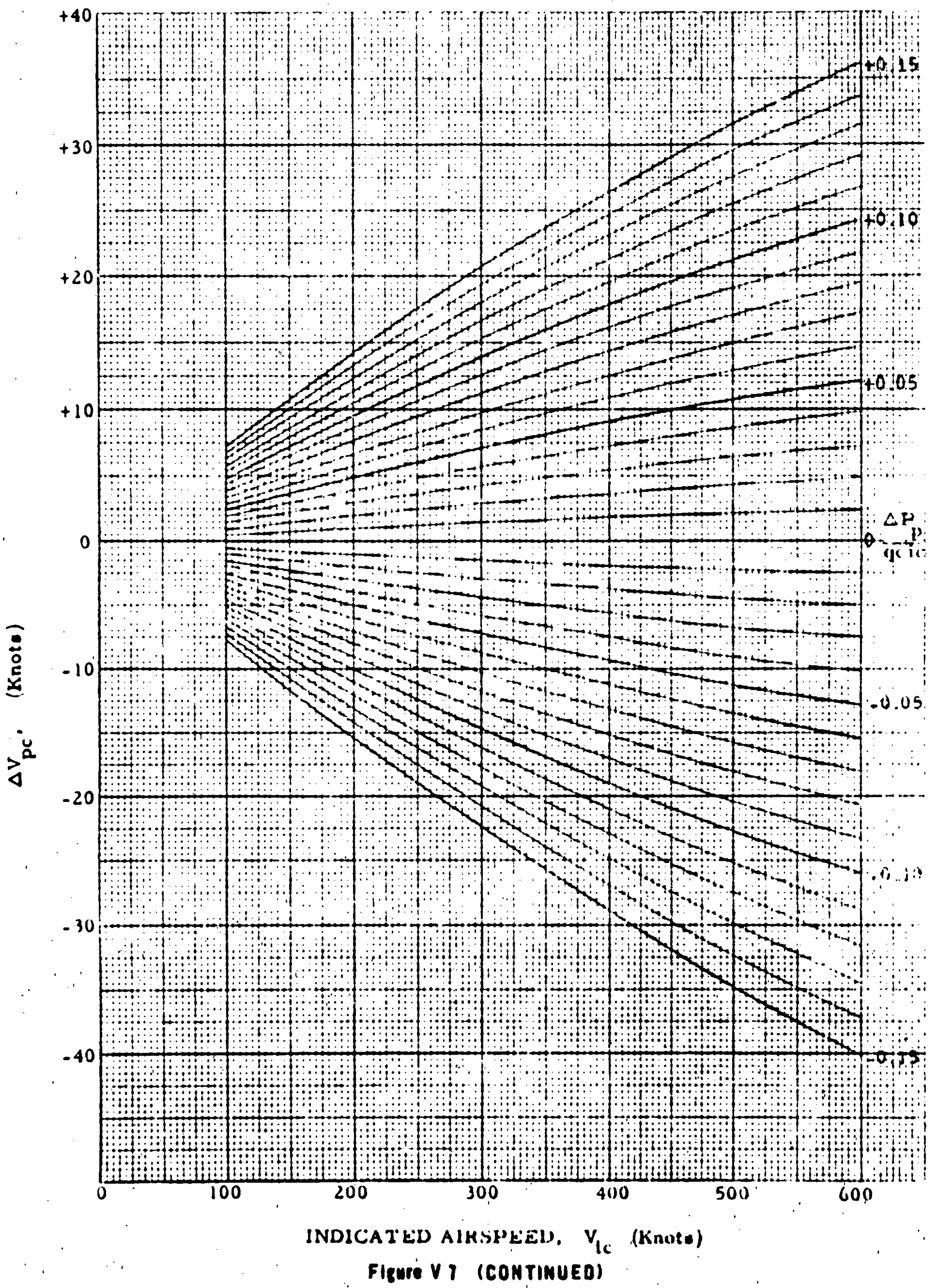


Figure V 7 (CONTINUED)

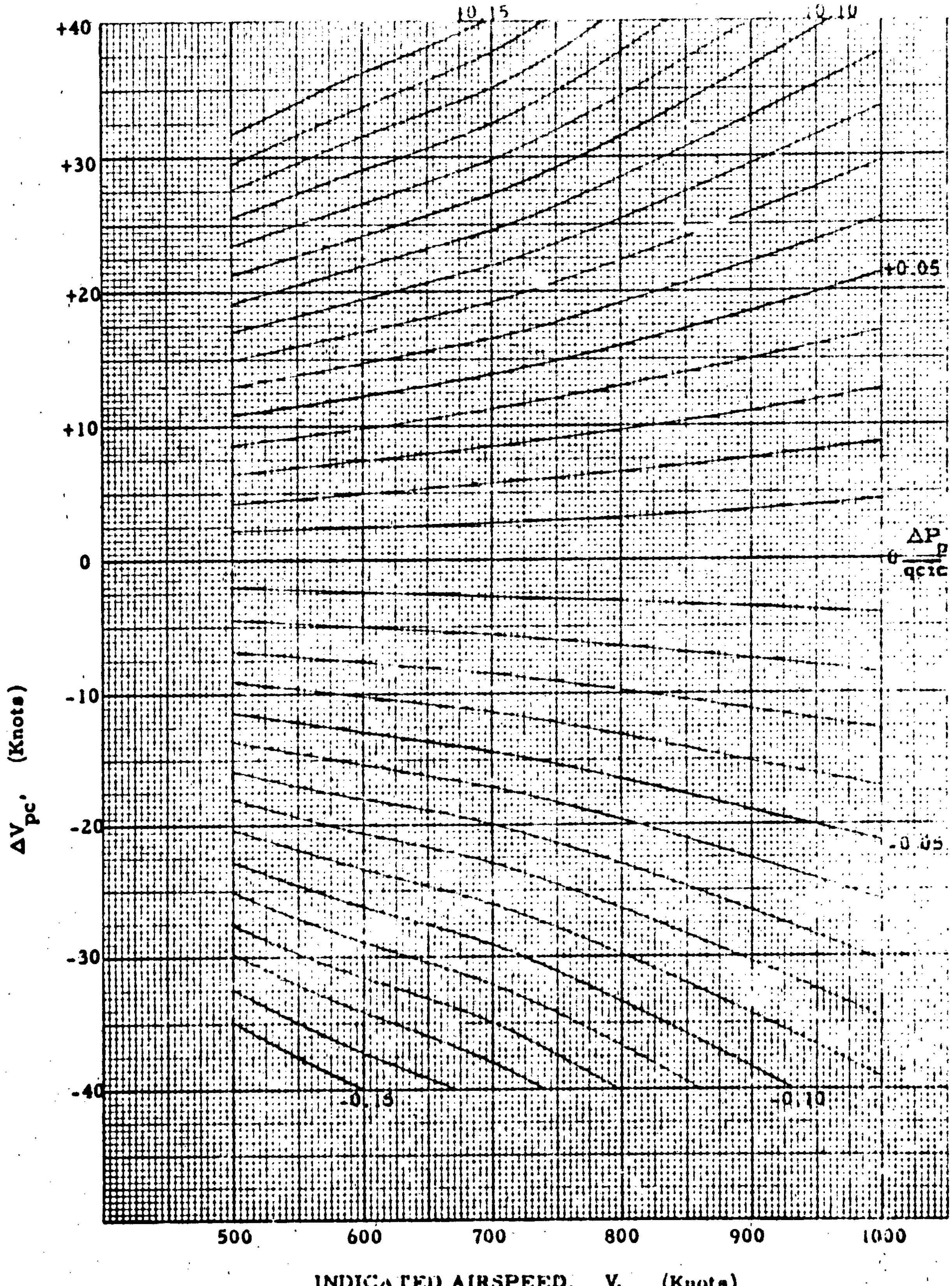


Figure V-7 (CONCLUDED)

RATIO OF ALTIMETER TO AIRSPEED INDICATOR POSITION ERROR CORRECTIONS, $\Delta H_{pc}/\Delta V_{pc}$ (feet/knots) versus INDICATED AIRSPEED CORRECTED FOR INSTRUMENT ERROR, V_{ic} (knots) for INDICATED PRESSURE ALTITUDE CORRECTED FOR INSTRUMENT ERROR, H_{ic} (feet) = CONSTANT

$$\frac{\Delta H_{pc}}{\Delta V_{pc}} = \frac{58.566}{\sigma_s} \left(\frac{V_{ic}}{a_{SL}}\right) \left[1 + 0.2\left(\frac{V_{ic}}{a_{SL}}\right)^2\right]^{2.5} \qquad V_{ic} \leq a_{SL}$$

$$\frac{\Delta H_{pc}}{\Delta V_{pc}} = \frac{48,880}{\sigma_s} \left(\frac{V_{ic}}{a_{SL}}\right)^6 \frac{[2(V_{ic}/a_{SL})^2 - 1]}{[7(V_{ic}/a_{SL})^2 - 1]}^{3.5} \qquad V_{ic} \geq a_{SL}$$

where σ_s is measured at H_{ic} and a_{SL} = 661.48 knots

Note: This curve is valid for small errors only, (say ΔH_{pc} < 1000 feet or ΔV_{pc} < 10 knots). Chart 8.13 should be used for larger errors. **(Reference 1, P. 225)**

Example:

Given: H_{ic} = 20,000 feet; V_{ic} = 600 knots; ΔH_{pc} = 2000 feet

Required: ΔV_{pc} in knots

Solution: For the given conditions

$\Delta H_{pc}/\Delta V_{pc}$ = 147 feet/knots

$$\Delta V_{pc} = \frac{\Delta H_{pc}}{\Delta H_{pc}/\Delta V_{pc}} = 13.6 \text{ knots}$$

Figure V 8 $\Delta H_{pc}/\Delta V_{pc}$ vs Indicated Airspeed

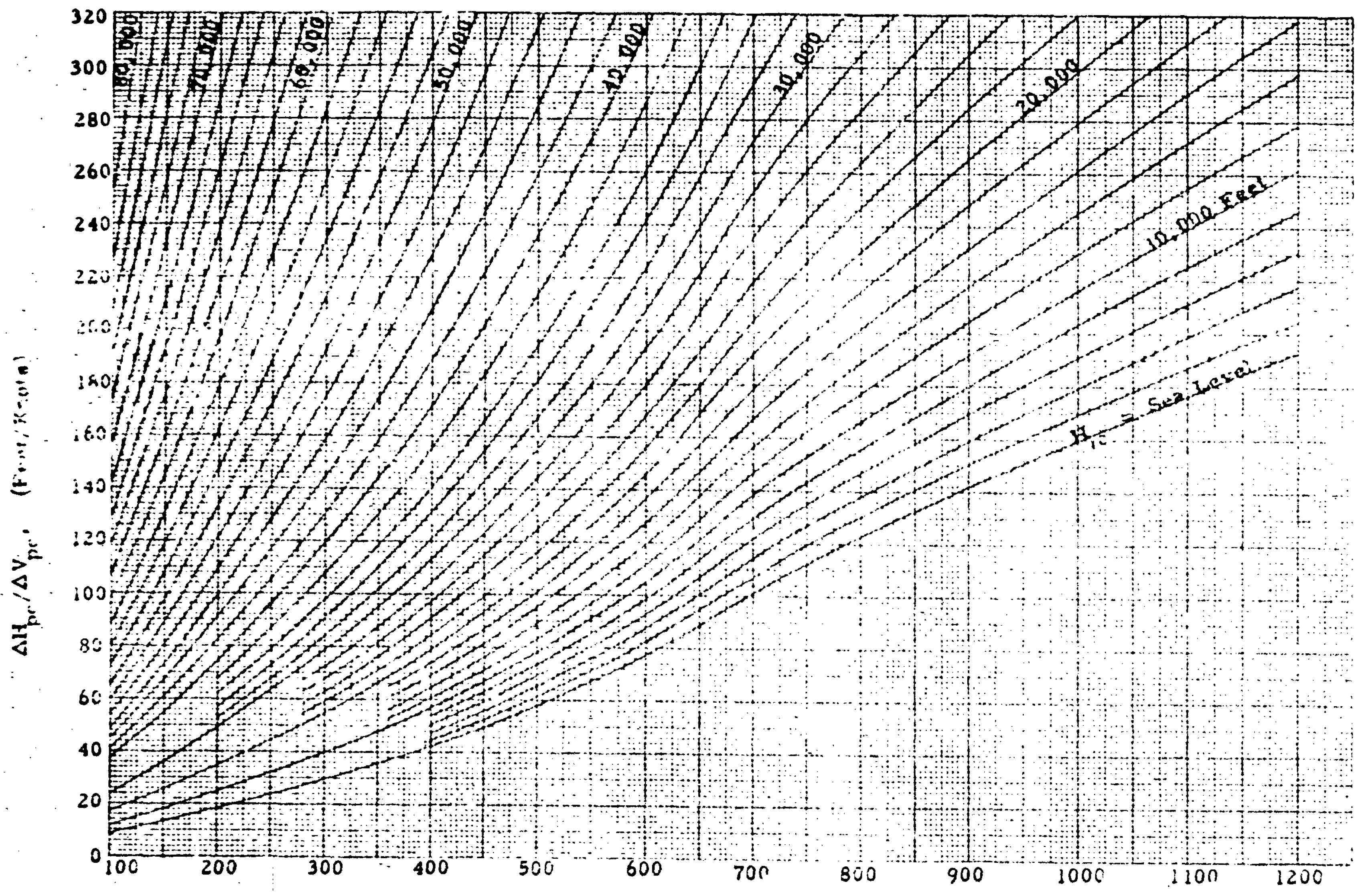
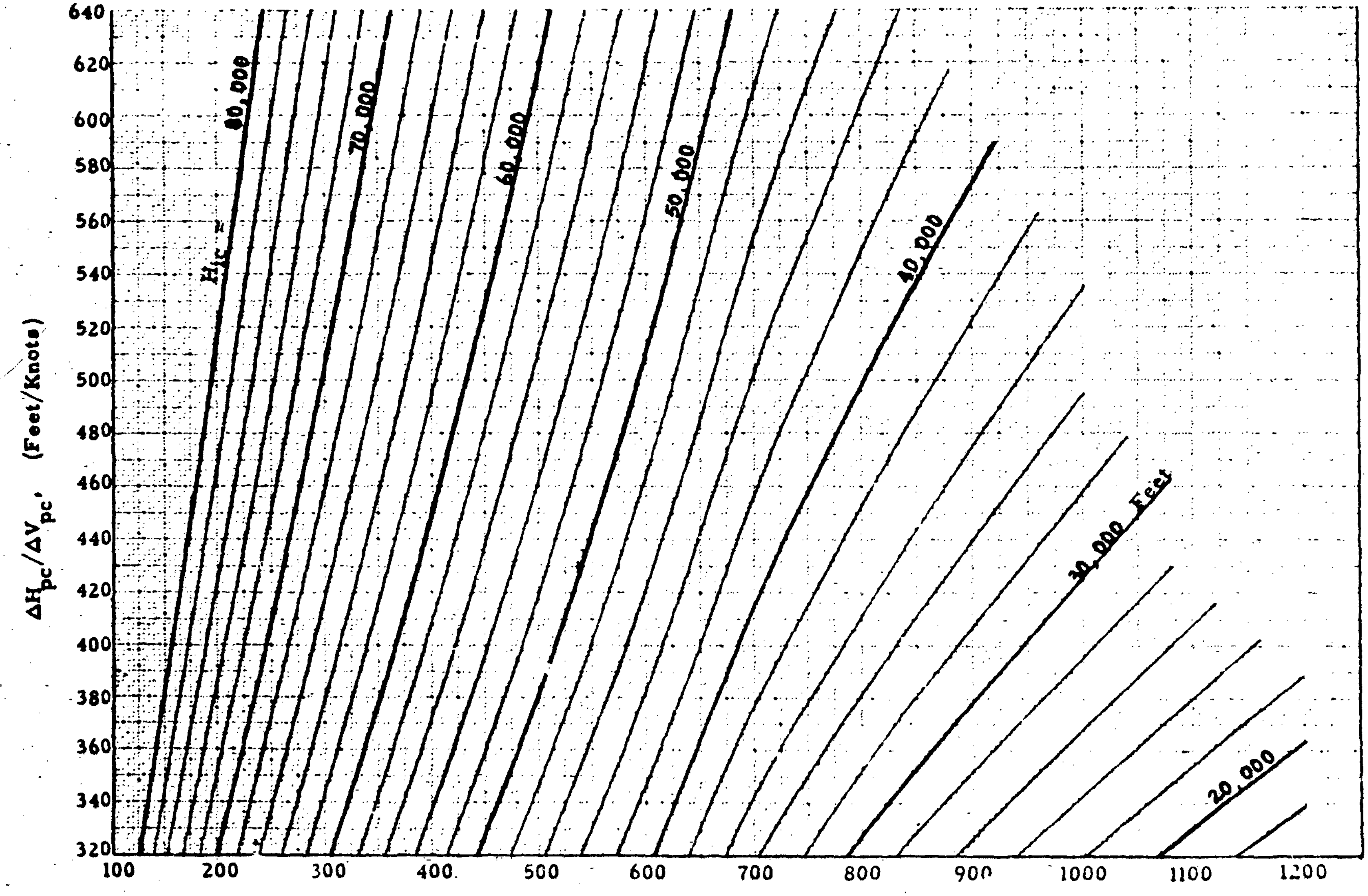


Figure V 8 (CONTINUED)



INDICATED AIRSPEED, V_{ic} (Knots)

Figure V 8 (CONTINUED)

Ref: AFFTC-TN-59-22
Chart 8.12

$$\frac{\Delta H_{pc}}{\Delta V_{pc}} = \frac{58.566}{\sigma_s}\left(\frac{V_{ic}}{a_{sl}}\right)\left[1 + 0.2\left(\frac{V_{ic}}{a_{sl}}\right)^2\right]^{2/5}$$

for $V_{ic} \leq a_{sl}$

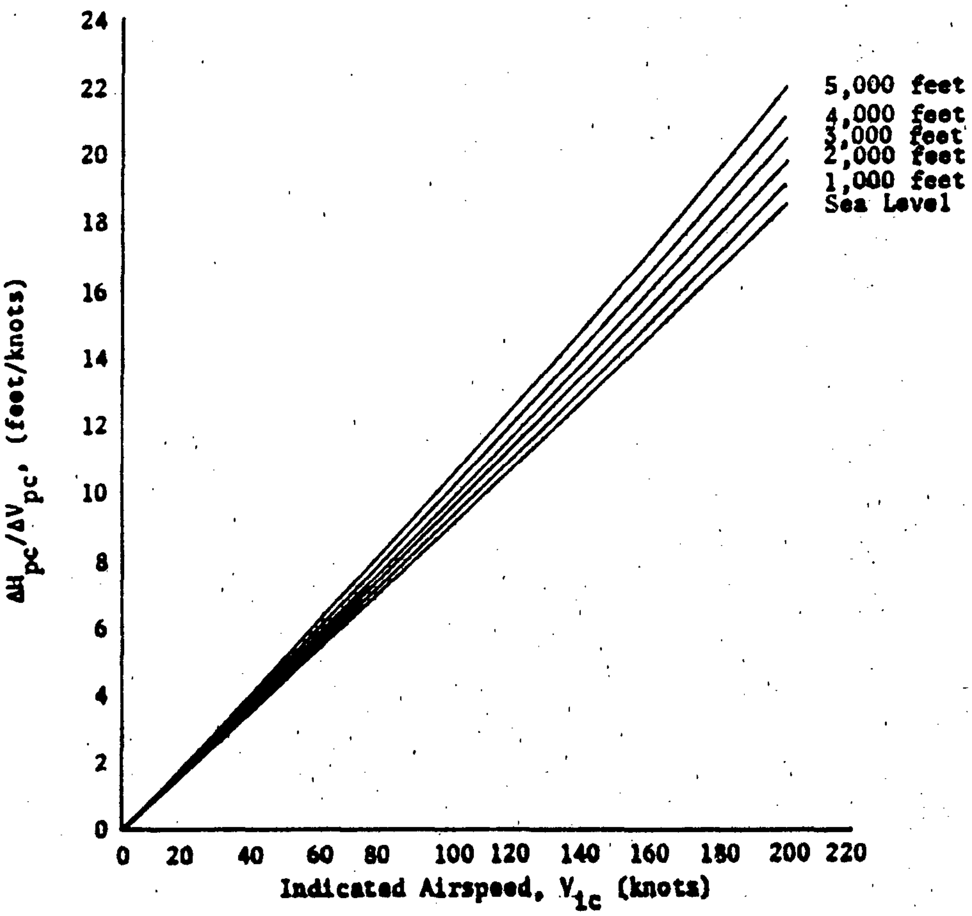


Figure V 8 (concl.) $\Delta H_{pc}/\Delta V_{pc}$ vs Indicated Airspeed

INDICATED MACH NUMBER CORRECTED FOR INSTRUMENT ERROR, M_{ic} versus RATIO OF MACH METER TO ALTIMETER POSITION ERROR CORRECTIONS, $\Delta M_{pc}/\Delta H_{pc}$ (1/feet) for INDICATED PRESSURE ALTITUDE CORRECTED FOR INSTRUMENT ERROR, H_{ic} (feet) = CONSTANT

$$\frac{\Delta M_{pc}}{\Delta H_{pc}} = 0.007438 \frac{(1 + 0.2 M_{ic}^2)}{T_{as} M_{ic}} \qquad M_{ic} \leq 1.00$$

$$\frac{\Delta M_{pc}}{\Delta H_{pc}} = 0.001488 \frac{M_{ic}}{T_{as}} \frac{(7M_{ic}^2 - 1)}{(2M_{ic}^2 - 1)} \qquad M_{ic} \geq 1.00$$

where T_{as} is measured at H_{ic}.

Note: This curve is valid for small errors only, (say $\Delta H_{pc} < 1000$ feet or $\Delta M_{pc} < 0.04$). Chart 8.15 should be used for large errors. (Reference 1, P. 238)

Figure V 9 $\Delta M_{pc}/\Delta H_{pc}$ vs Indicated Mach Number

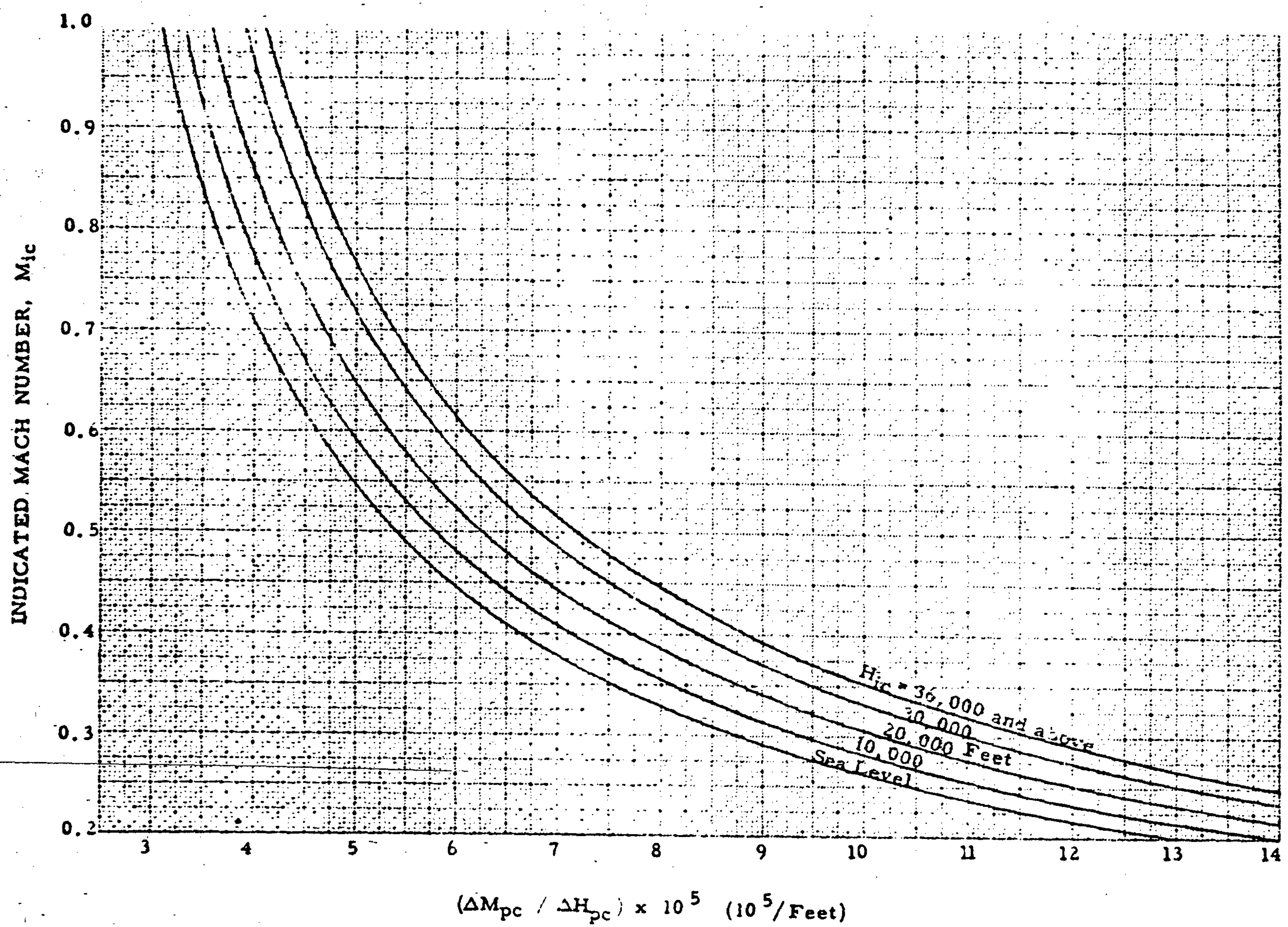


Figure V 9 (CONCLUDED)

INDICATED MACH NUMBER CORRECTED FOR INSTRUMENT ERROR; M_{ic} versus RATIO OF MACH METER POSITION ERROR CORRECTION TO POSITION ERROR PRESSURE COEFFICIENT, $\Delta M_{pc}/(\Delta P_p/q_{cic})$

$$\frac{\Delta M_{pc}}{(\Delta P_p/q_{cic})} = \frac{(1 + 0.2\,M_{ic}^2)}{1.4\,M_{ic}}\left[(1 + 0.2\,M_{ic}^2)^{3.5} - 1\right] \qquad M_{ic} \le 1.00$$

$$\frac{\Delta M_{pc}}{(\Delta P_p/q_{cic})} = \frac{M_{ic}\left[166.921\,M_{ic}^7 - (7M_{ic}^2 - 1)^{2.5}\right]}{7(7\,M_{ic}^2 - 1)^{1.5}\,(2\,M_{ic}^2 - 1)} \qquad M_{ic} \ge 1.00$$

Note: This curve is valid for small errors only, (say $\Delta M_{pc} < 0.04$ or $\Delta P_p/q_{cic} < 0.04$). Chart 8.18 should be used for larger errors. (Reference 1, P. 259)

Figure V 18 $\Delta M_{pc}/\Delta P_p/q_{c_{ic}}$ **vs Indicated Mach Number**

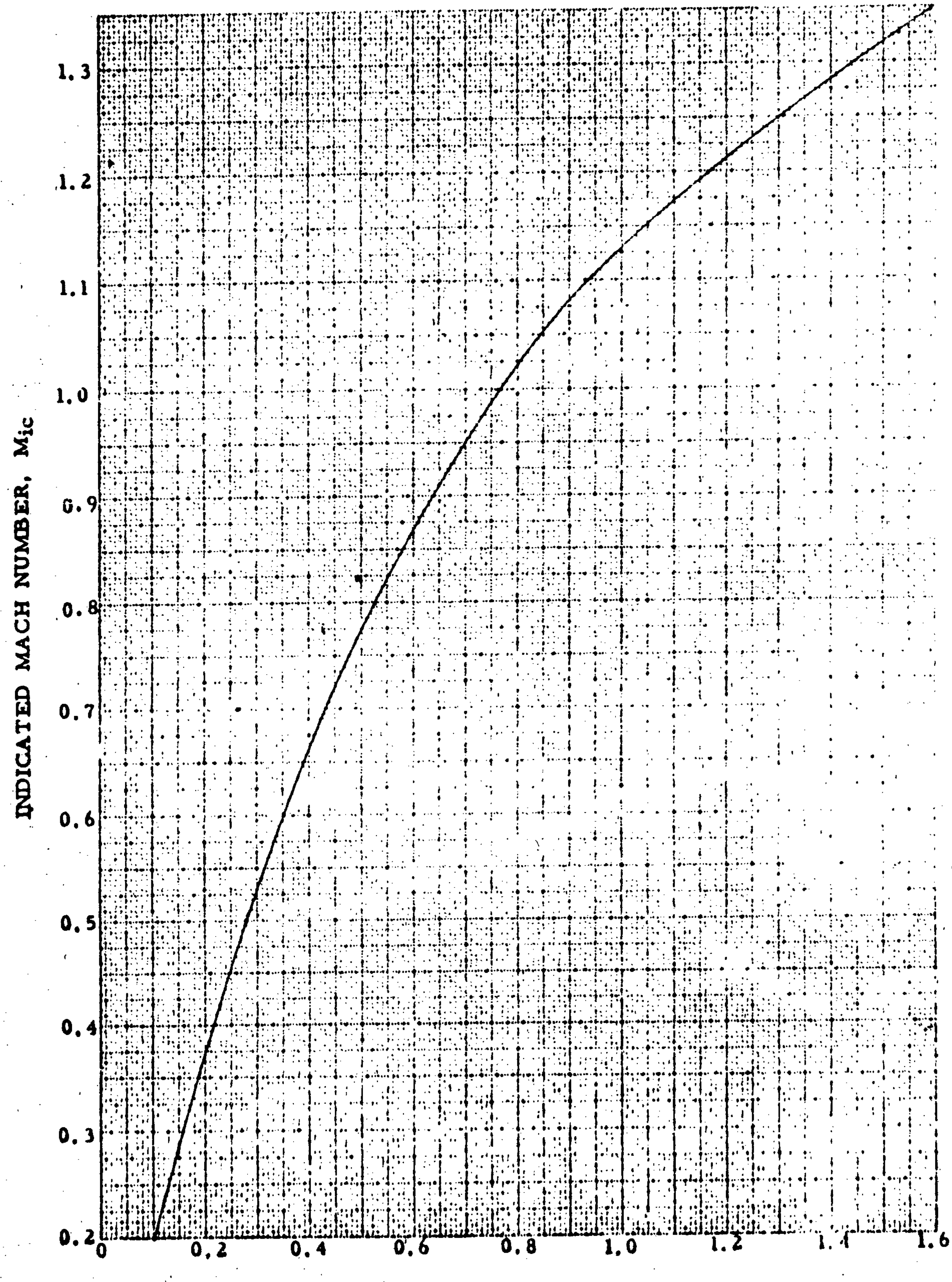


Figure V 18 (CONCLUDED)

STANDARD ALTITUDE TABLE

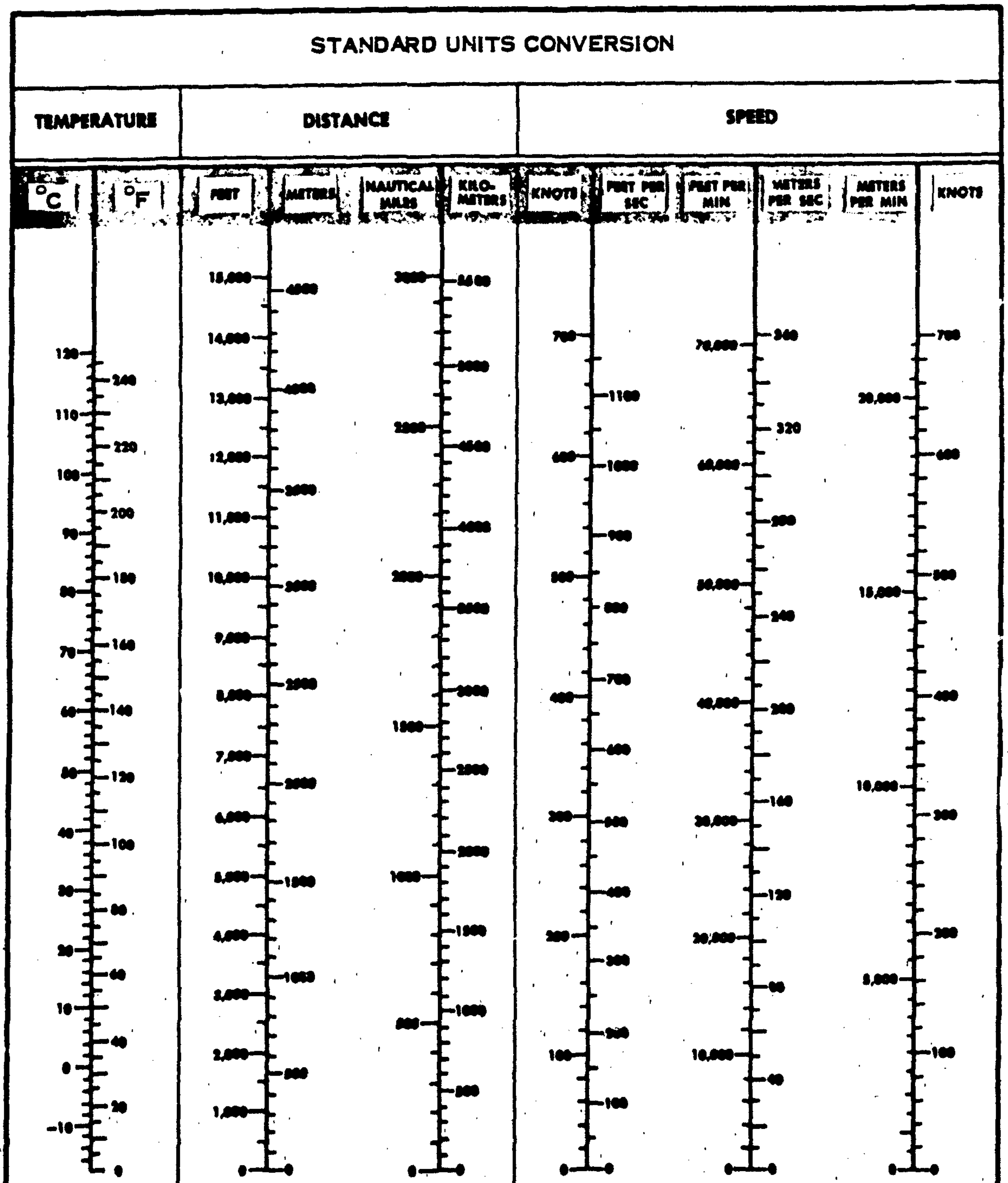
STANDARD SEA LEVEL AIR:
T = 59°F
P = 29.921 IN. OF HG

W = .076475 LB/CU FT ρ_o = .0023769 SLUGS/CU FT
1" OF HG = 70.732 LB/SQ FT 0.4912 LB/SQ IN
a_o = 1116.89 FT/SEC

BASED ON INTERNATIONAL CIVIL AVIATION ORGANIZATION (ICAO) STANDARD ATMOSPHERE
(NACA TECHNICAL REPORT NO. 1235)

ALTITUDE FEET	DENSITY RATIO ρ/ρ_o	$1/\sqrt{\sigma}$	TEMPERATURE DEG. F	TEMPERATURE DEG. C	SPEED OF SOUND RATIO a/a_o	PRESSURE IN. OF HG	PRESSURE RATIO P/P_o
—2000	1.0598	0.9714	66.132	18.962	1.0064	32.15	1.0294
—1000	1.0296	0.9855	62.566	16.981	1.0030	31.02	1.0147
0	1.0000	1.0000	59.000	15.000	1.0000	29.92	1.0000
1000	.9711	1.0148	55.434	13.019	.9966	28.86	.9644
2000	.9428	1.0299	51.868	11.038	.9931	27.82	.9298
3000	.9151	1.0454	48.302	9.057	.9896	26.82	.8962
4000	.8881	1.0611	44.735	7.075	.9862	25.84	.8637
5000	.8617	1.0773	41.169	5.094	.9827	24.90	.8320
6000	.8359	1.0938	37.603	3.113	.9792	23.98	.8014
7000	.8106	1.1107	34.037	1.132	.9756	23.09	.7716
8000	.7860	1.1279	30.471	— 0.849	.9721	22.27	.7428
9000	.7620	1.1456	26.905	— 2.831	.9686	21.39	.7148
10000	.7385	1.1637	23.338	— 4.812	.9650	20.58	.6877
11000	.7156	1.1822	19.772	— 6.793	.9614	19.79	.6614
12000	.6932	1.2011	16.206	— 8.774	.9579	19.03	.6360
13000	.6713	1.2205	12.640	—10.756	.9543	18.29	.6113
14000	.6500	1.2403	9.074	—12.737	.9507	17.58	.5875
15000	.6292	1.2606	5.508	—14.718	.9470	16.89	.5643
16000	.6090	1.2815	1.941	—16.699	.9434	16.22	.5420
17000	.5892	1.3028	— 1.625	—18.681	.9397	15.57	.5203
18000	.5699	1.3246	— 5.191	—20.662	.9361	14.94	.4994
19000	.5511	1.3470	— 8.757	—22.643	.9324	14.34	.4791
20000	.5328	1.3700	—12.323	—24.624	.9287	13.75	.4595
21000	.5150	1.3935	—15.889	—26.605	.9250	13.18	.4406
22000	.4976	1.4176	—19.456	—28.587	.9213	12.64	.4223
23000	.4807	1.4424	—23.022	—30.568	.9175	12.11	.4046
24000	.4642	1.4678	—26.588	—32.549	.9138	11.60	.3876
25000	.4481	1.4938	—30.154	—34.530	.9100	11.10	.3711
26000	.4325	1.5206	—33.720	—36.511	.9062	10.63	.3552
27000	.4173	1.5480	—37.286	—38.492	.9024	10.17	.3398
28000	.4025	1.5762	—40.852	—40.473	.8986	9.725	.3250
29000	.3881	1.6052	—44.419	—42.455	.8948	9.297	.3107
30000	.3741	1.6349	—47.985	—44.436	.8909	8.885	.2970
31000	.3605	1.6654	—51.551	—46.417	.8871	8.488	.2837
32000	.3473	1.6968	—55.117	—48.398	.8832	8.10[illegible]	.2709
33000	.3345	1.7291	—58.683	—50.379	.8793	7.737	.2586
34000	.3220	1.7623	—62.249	—52.361	.8754	7.382	.2467
35000	.3099	1.7964	—65.816	—54.342	.8714	7.04[illegible]	.2353
36000	.2981	1.8315	—69.382	—56.323	.8675	6.71[illegible]	.2243
37000	.2844	1.8753	—69.700	—56.500	.8671	6.39[illegible]	.2138
38000	.2710	1.9209	—69.700	—56.500	.8671	6.09[illegible]	.2038
39000	.2583	1.9677	—69.700	—56.500	.8671	5.81[illegible]	.1942
40000	.2462	2.0155	—69.700	—56.500	.8671	5.538	.1851
41000	.2346	2.0645	—69.700	—56.500	.8671	5.278	.1764
42000	.2236	2.1148	—69.700	—56.500	.8671	5.030	.1681
43000	.2131	2.1662	—69.700	—56.500	.8671	4.794	.1602
44000	.2031	2.2189	—69.700	—56.500	.8671	4.[illegible]9	.1527
45000	.1936	2.2728	—69.700	—56.500	.8671	4.355	.1455
46000	.1845	2.3281	—69.700	—56.500	.8671	4.151	.1387
47000	.1758	2.3848	—69.700	—56.500	.8671	3.956	.1322
48000	.1676	2.4428	—69.700	—56.500	.8671	3.77[illegible]	.1260
49000	.1597	2.5022	—69.700	—56.500	.8671	3.593	.1201
50000	.1522	2.5630	—69.700	—56.500	.8671	3.425	.1145
51000	.1451	2.6254	—69.700	—56.500	.8671	3.264	.1091
52000	.1383	2.6892	—69.700	—56.500	.8671	3.111	.1040
53000	.1318	2.7546	—69.700	—56.500	.8671	2.965	.09909
54000	.1256	2.8216	—69.700	—56.500	.8671	2.826	.09444
55000	.1197	2.8903	—69.700	—56.500	.8671	2.693	.0[illegible]
56000	.1141	2.9606	—69.700	—56.500	.8671	2.567	.08578
57000	.1087	3.0326	—69.700	—56.500	.8671	2.446	.08176
58000	.1036	3.1063	—69.700	—56.500	.8671	2.331	.07792
59000	.09877	3.1819	—69.700	—56.500	.8671	2.222	.07426
60000	.09414	3.2593	—69.700	—56.500	.8671	2.118	.07078
61000	.08972	3.3386	—69.700	—56.500	.8671	2.018	.06746
62000	.08551	3.4198	—69.700	—56.500	.8671	1.924	.06429
63000	.08150	3.5029	—69.700	—56.500	.8671	1.833	.06127
64000	.07767	3.5881	—69.700	—56.500	.8671	1.747	.05840
65000	.07403	3.6754	—69.700	—56.500	.8671	1.665	.05566

Figure V 11 STANDARD ALTITUDE TABLE



NOTE:

TO OBTAIN U S GALLONS MULTIPLY LITERS BY 0.264

TO OBTAIN IMPERIAL GALLONS MULTIPLY LITERS BY 0.220

TO OBTAIN INCHES OF MERCURY MULTIPLY MILLIBARS BY .0295

TO OBTAIN POUNDS MULTIPLY KILOGRAMS BY 2.20

Figure V 12 STANDARD CONVERSION CHART

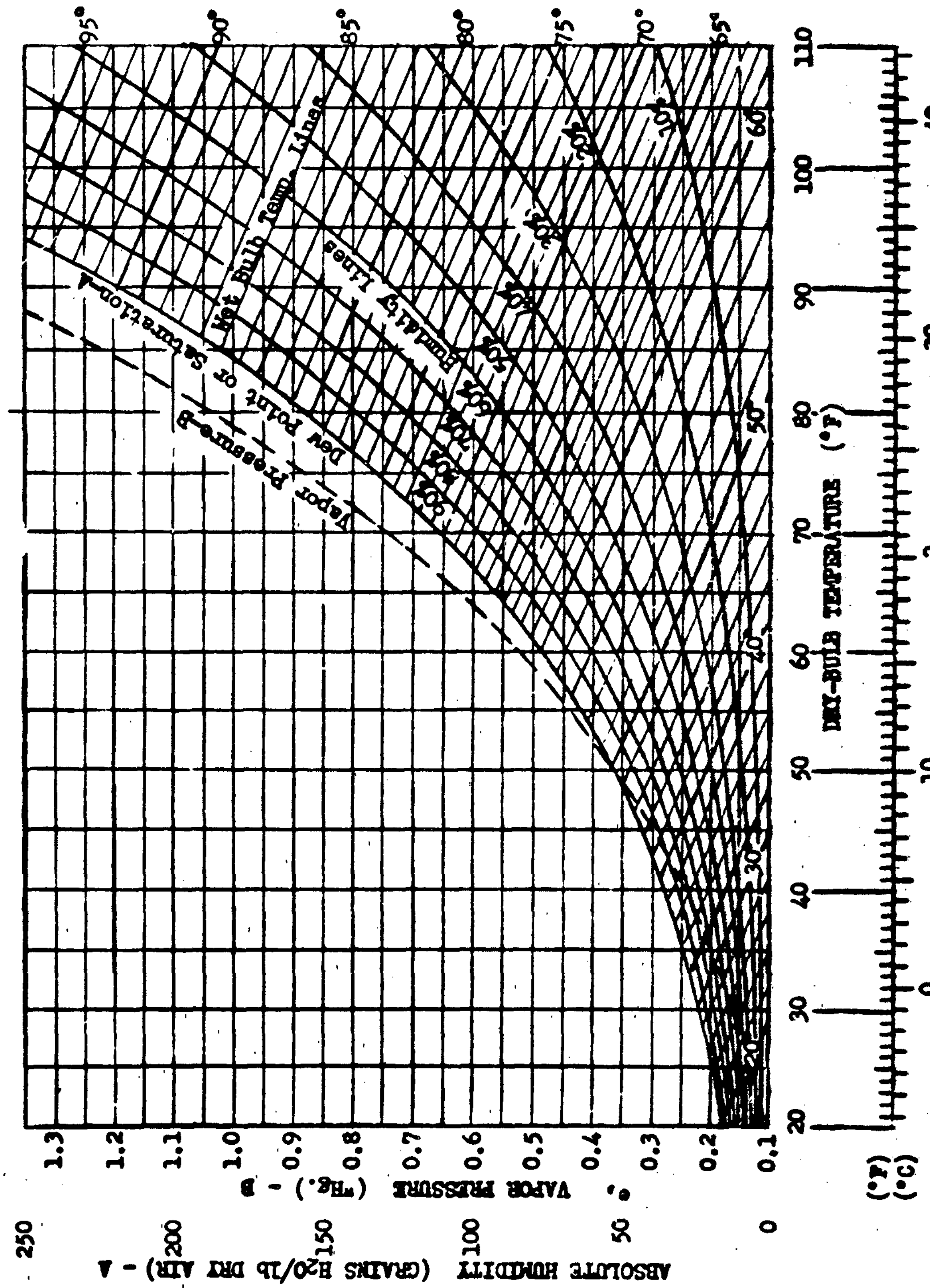


Figure V 13 PSYCHROMETRIC CHART

AIRSPEED/MACH NUMBER CONVERSION

MACH NUMBER, M versus CALIBRATED AIRSPEED, V_c for PRESSURE ALTITUDE, H_c = CONSTANT

and

MACH NUMBER, M versus CALIBRATED AIRSPEED, V_c for STANDARD DAY TRUE SPEED, V_{ts} = CONSTANT

also

INDICATED MACH NUMBER CORRECTED FOR INSTRUMENT ERROR, M_{ic} versus INDICATED AIRSPEED CORRECTED FOR INSTRUMENT ERROR, V_{ic} for INDICATED PRESSURE ALTITUDE CORRECTED FOR INSTRUMENT ERROR, H_{ic} = CONSTANT

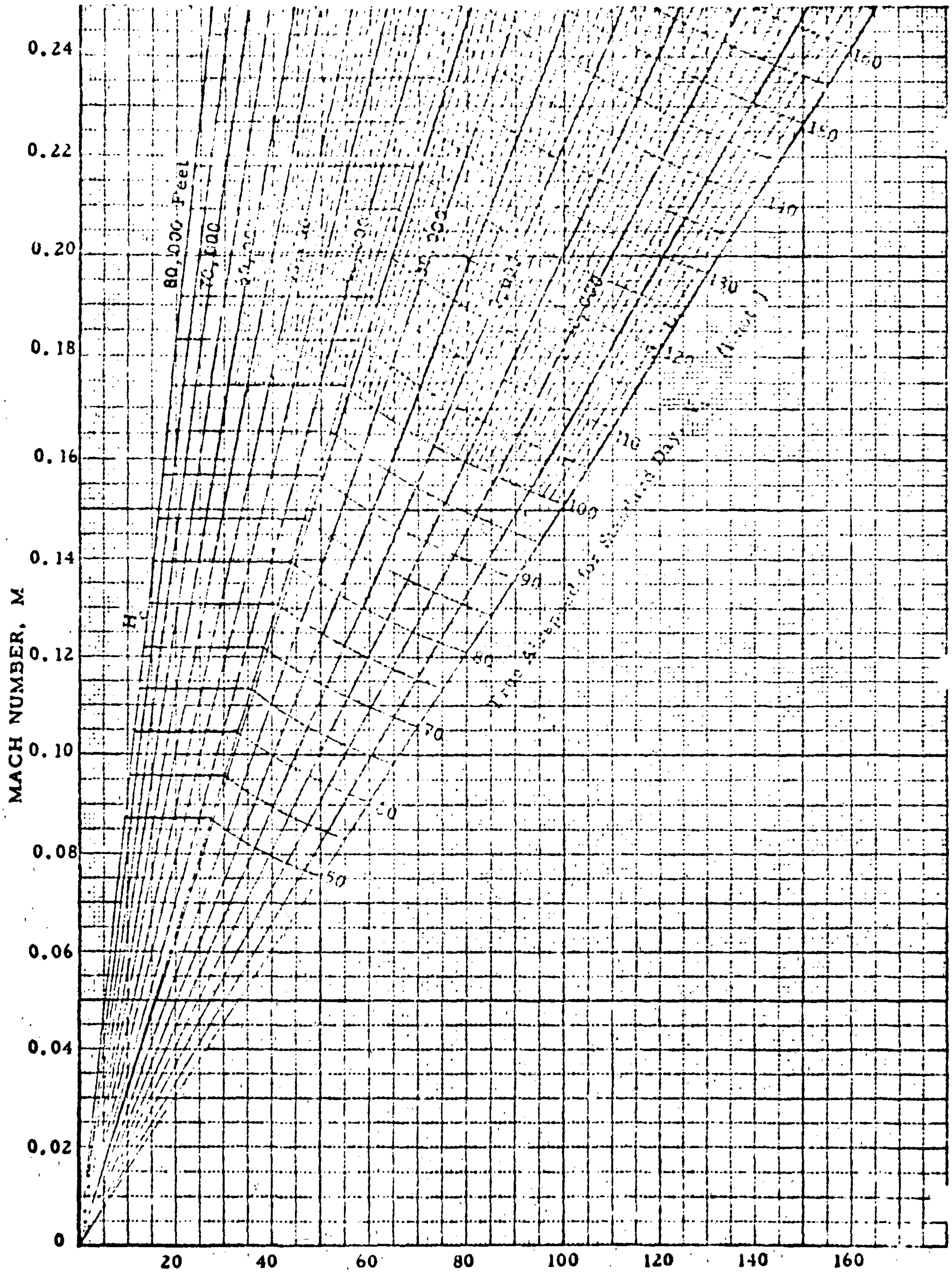


FIGURE V 14A CALIBRATED AIRSPEED, V_c (Knots)

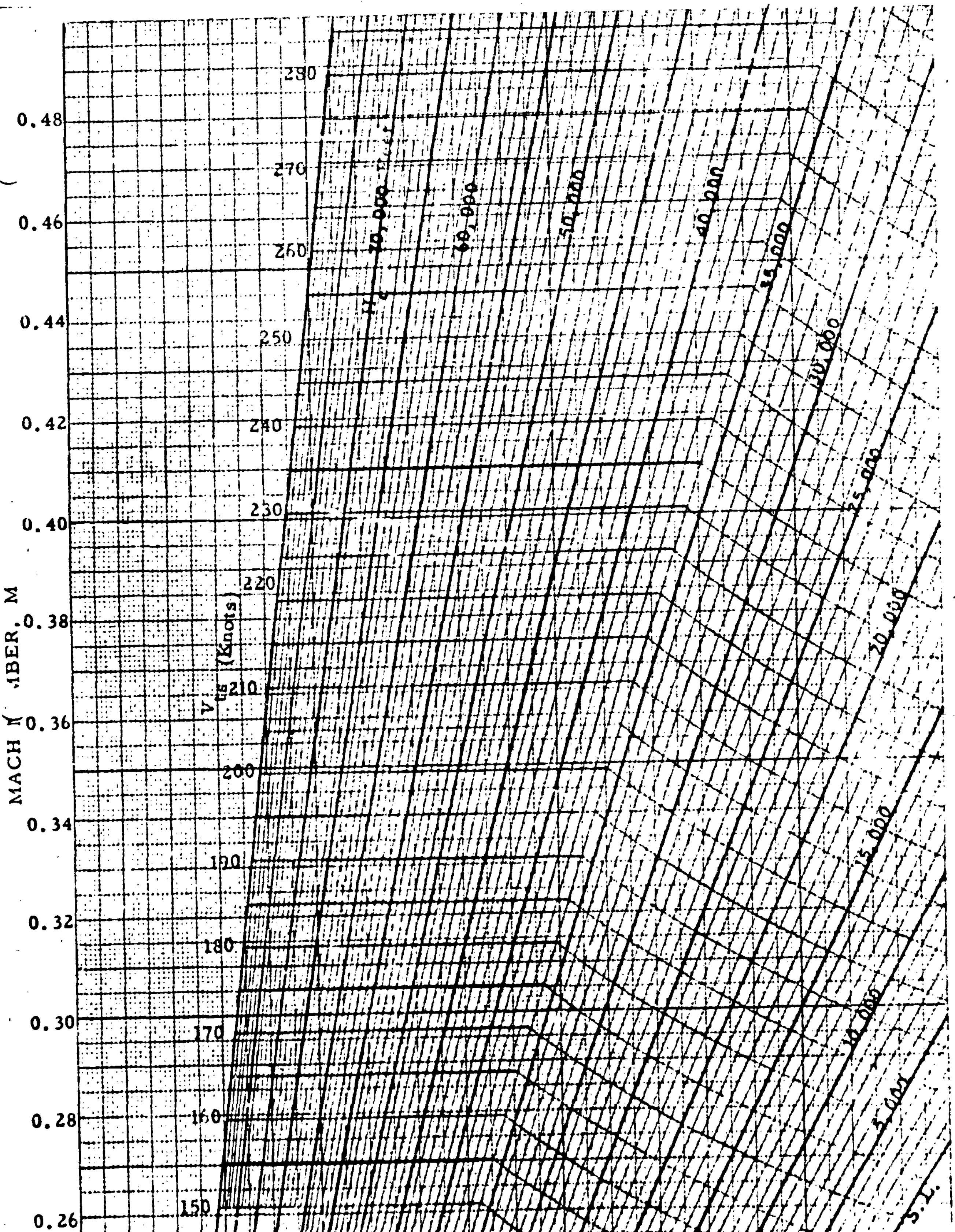

MACH NUMBER, M
0.48
0.46
0.44
0.42
0.40
0.38
0.36
0.34
0.32
0.30
0.28
0.26
0
20
40
60
80
100
120
140
CALIBRATED AIRSPEED, V_c (Knots)
V_{us} (Knots)
280
270
260
250
240
230
220
210
200
190
180
170
160
150
50,000
40,000
30,000
20,000
15,000
10,000
5,000
S.L.

FIGURE V 14B

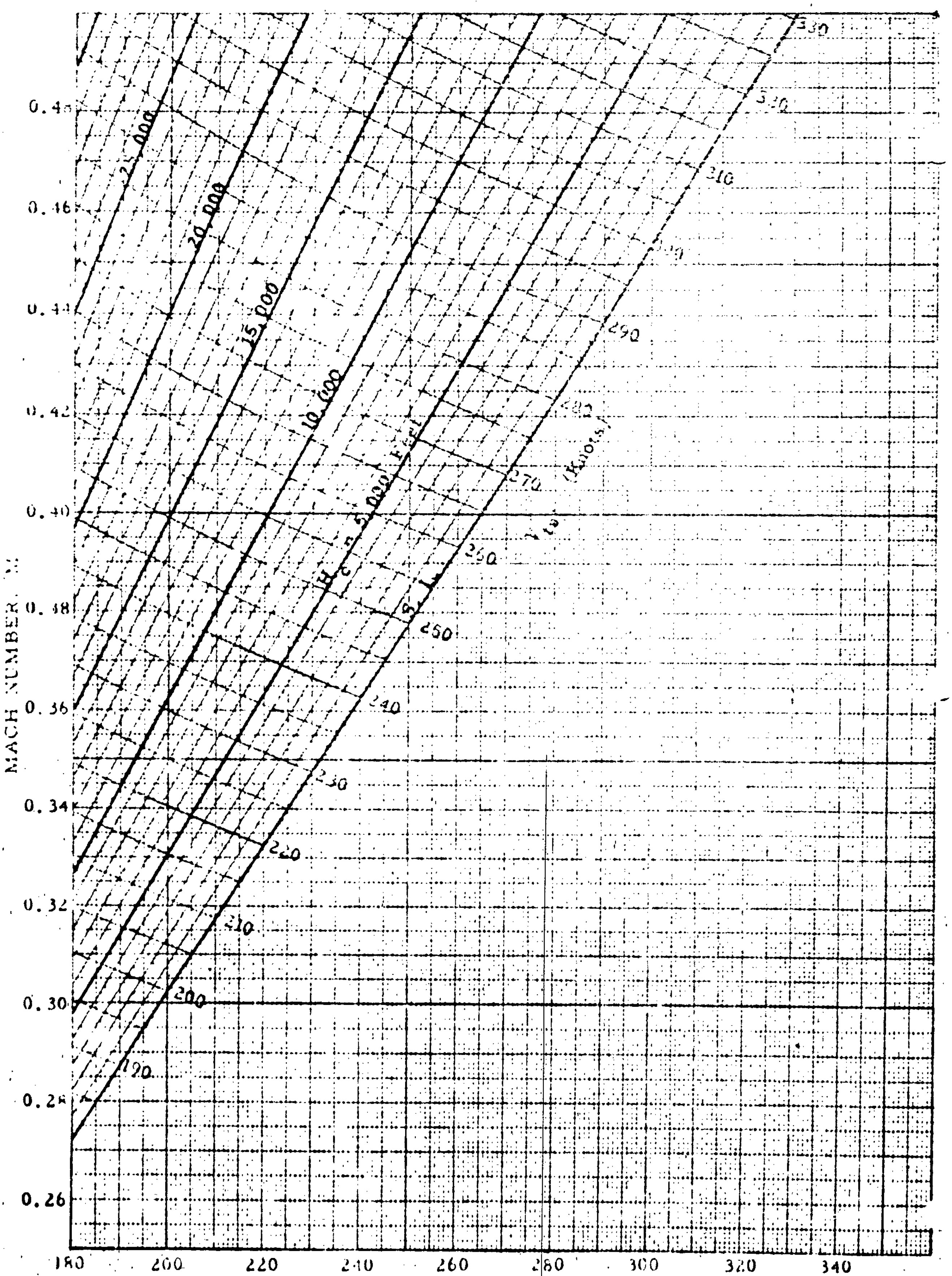


FIGURE V 14C   CALIBRATED AIRSPEED, V_c (Knots)

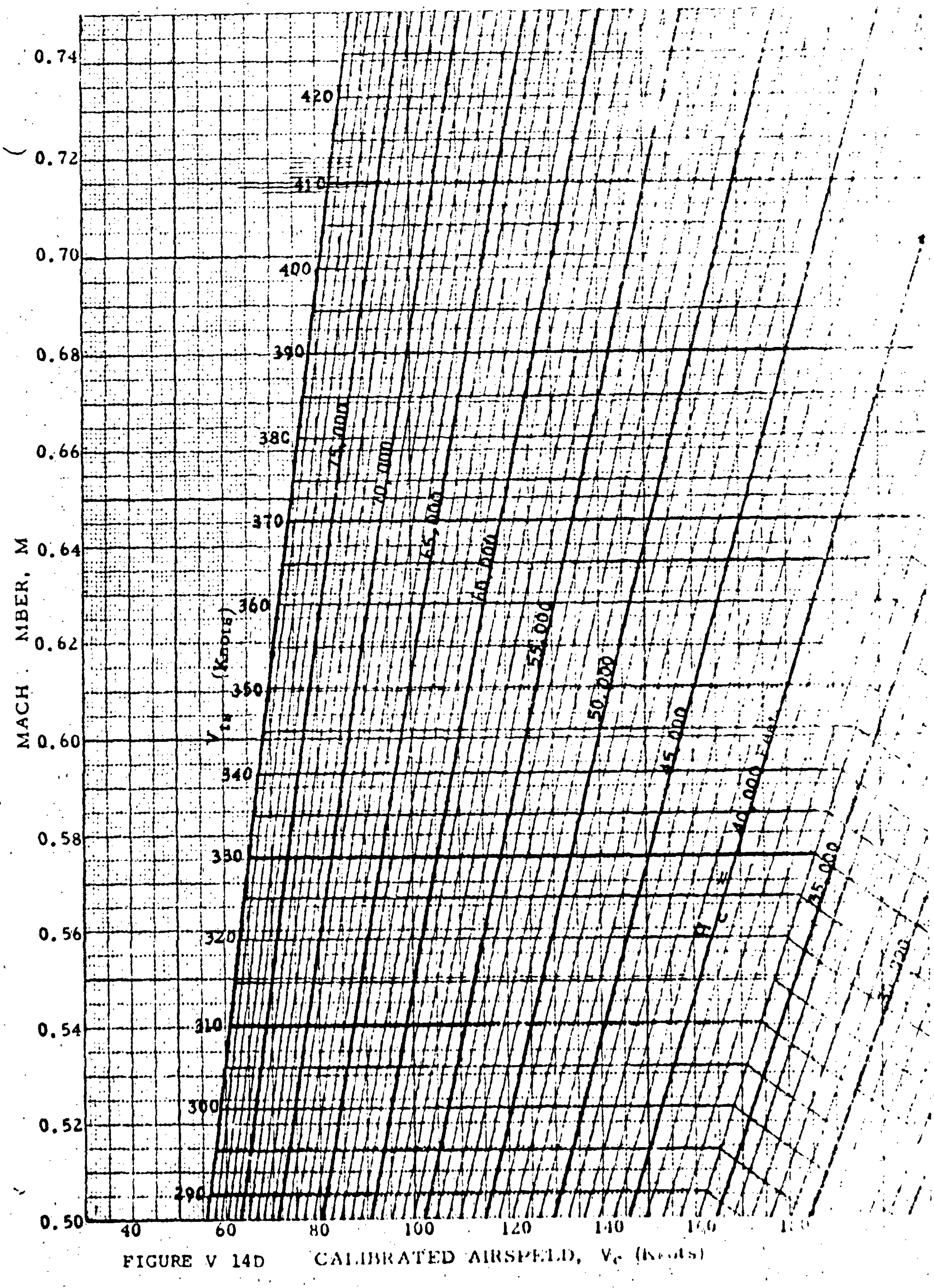


FIGURE V 14D CALIBRATED AIRSPEED, V_c (Knots)

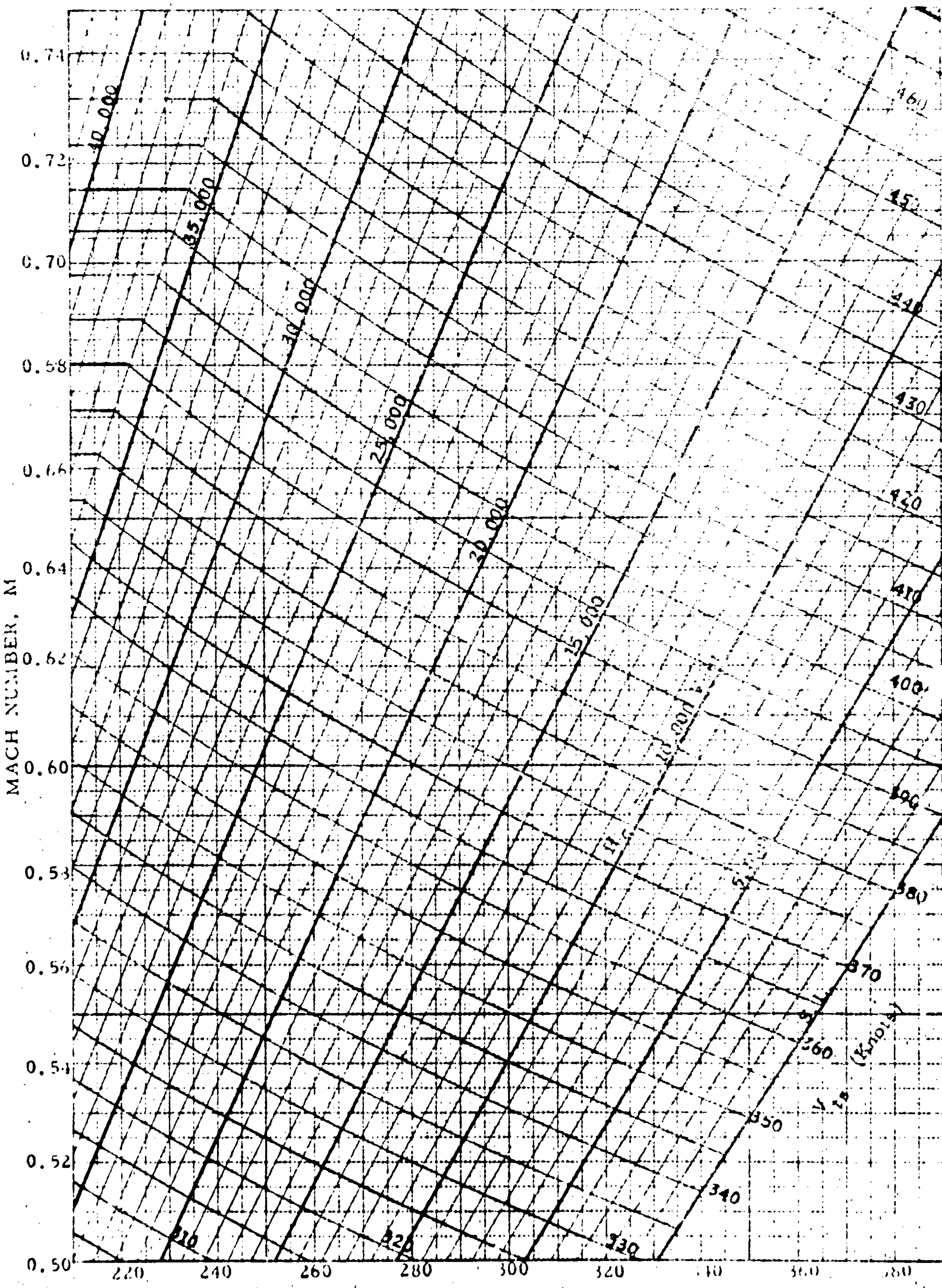


FIGURE V 14E CALIBRATED AIRSPEED, V_c (Knots)

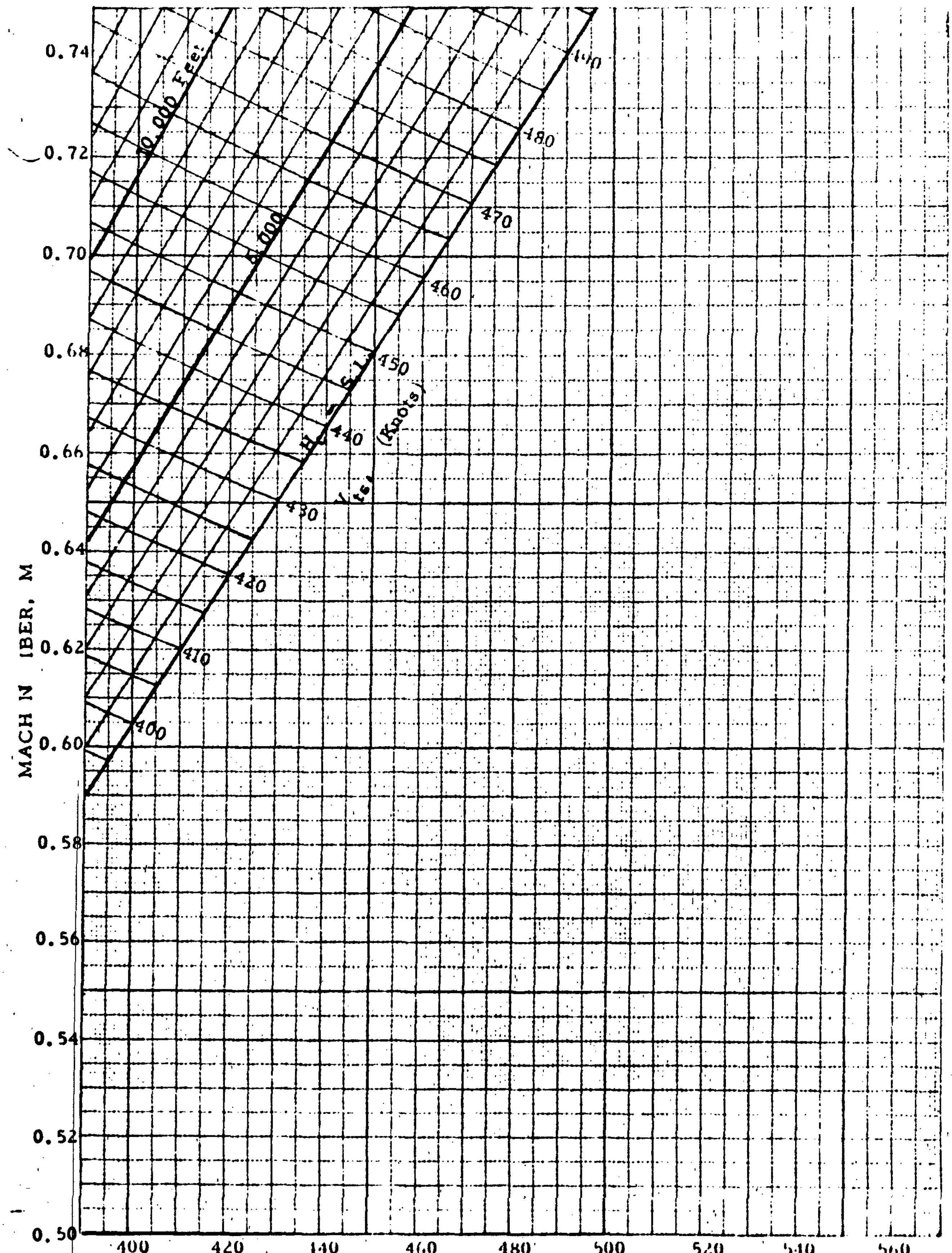
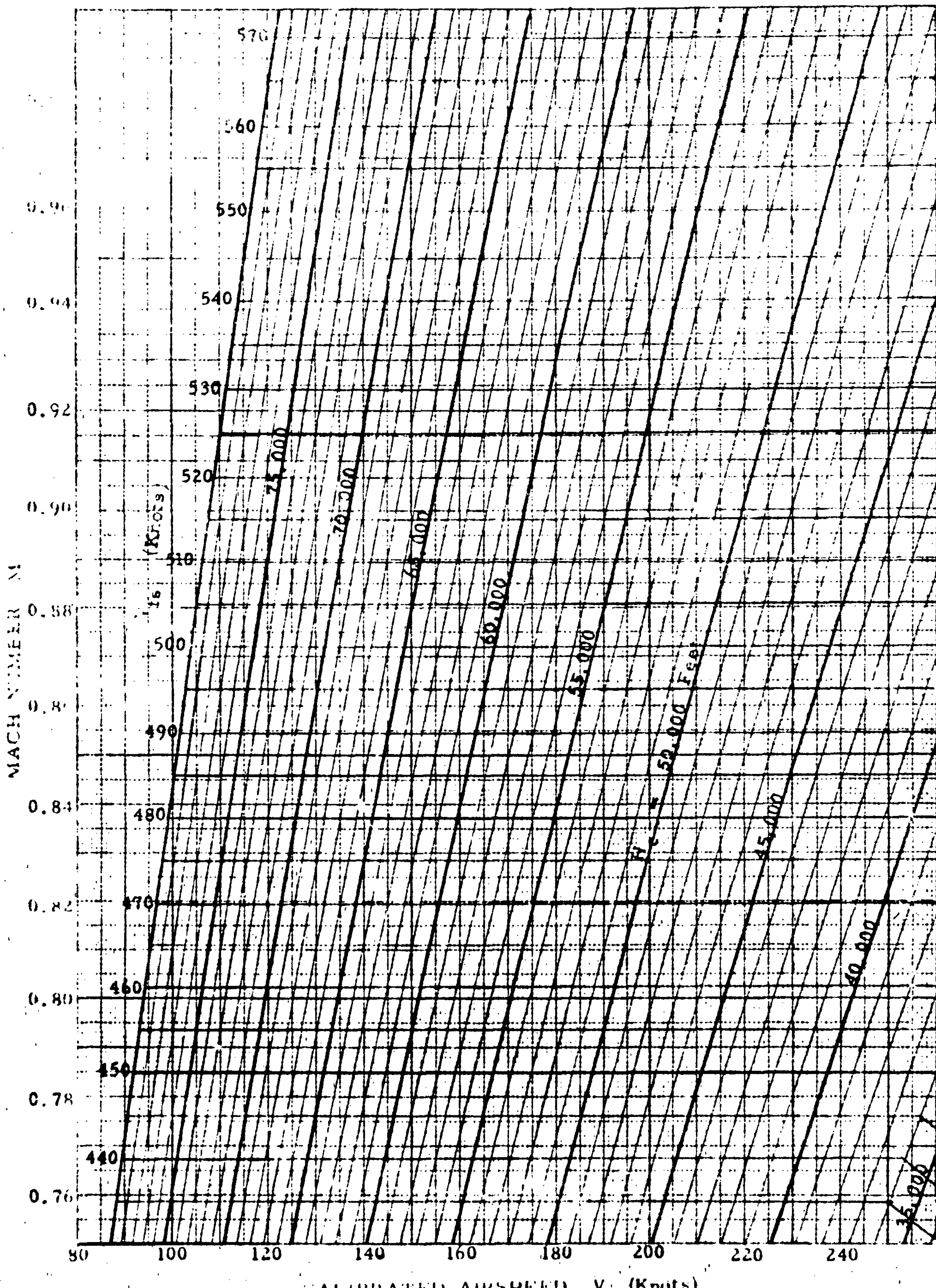
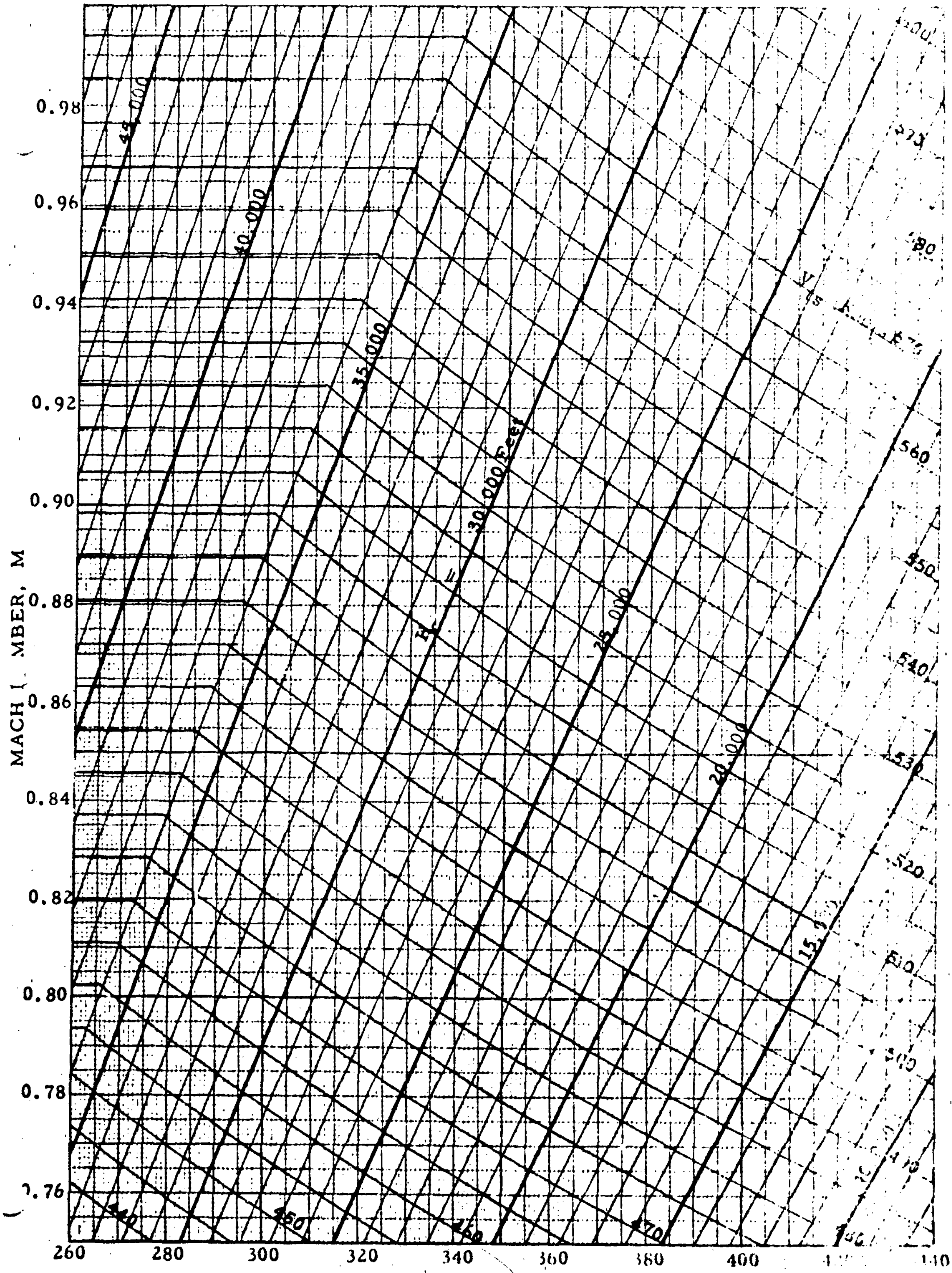


FIGURE V 14F CALIBRATED AIRSPEED, V_c (Knots)



MACH NUMBER M
0.76
0.78
0.80
0.82
0.84
0.88
0.92
0.94
440
450
460
470
480
490
500
510
520
530
540
550
560
570
(Knots)
75,000
70,000
65,000
60,000
55,000
H_c = 50,000 Feet
45,000
40,000
35,000
80
100
120
140
160
180
200
220
240
CALIBRATED AIRSPEED, V_c (Knots)

FIGURE V 14G



0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84
0.82
0.80
0.78
0.76
MACH NUMBER, M
45,000
40,000
35,000
30,000 Feet
25,000
20,000
15,000
H =
540
550
560
530
520
450
460
470
260
280
300
320
340
360
380
400
CALIBRATED AIRSPEED, V_c (Knots)

FIGURE V 14H

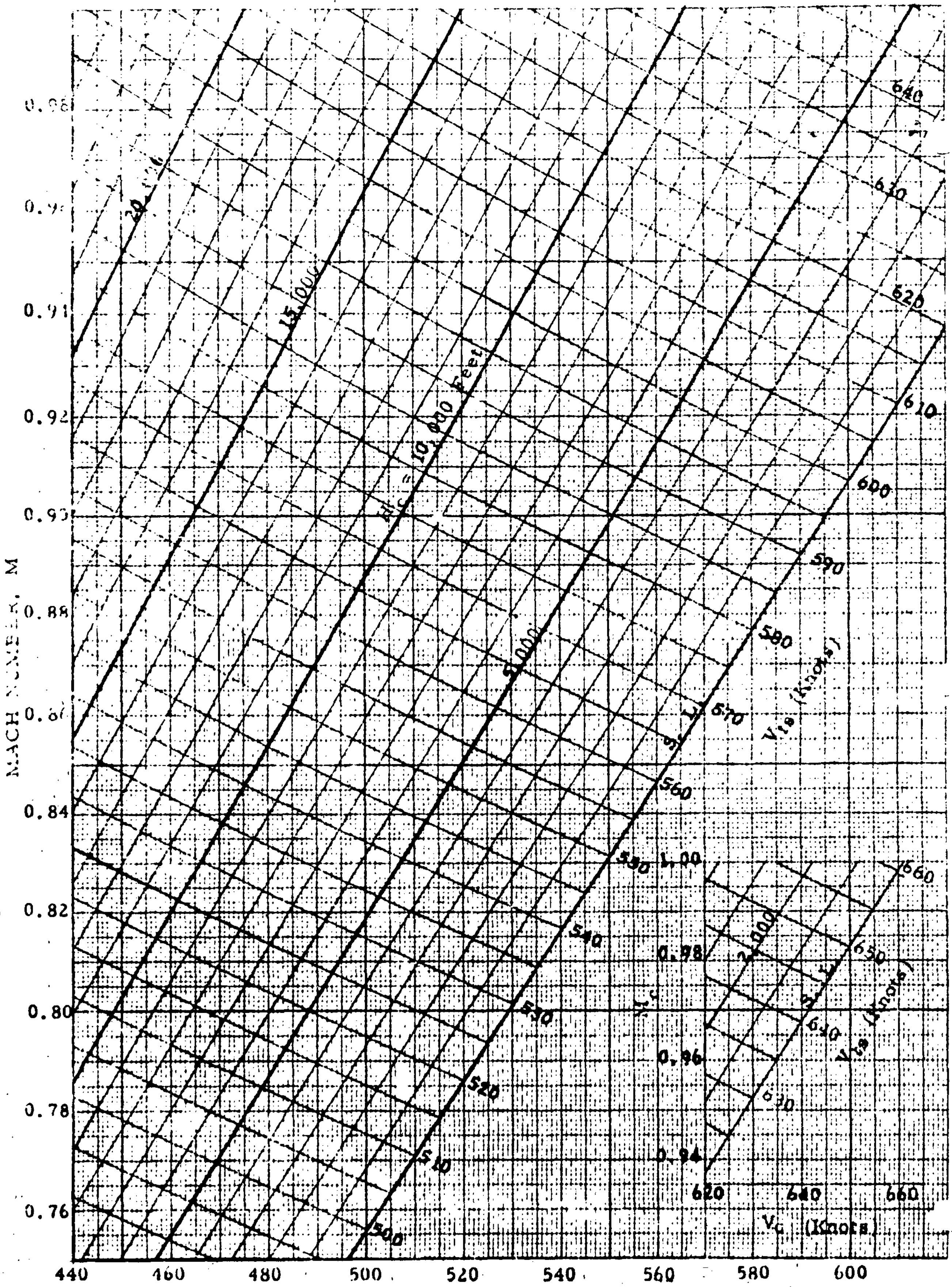


FIGURE V 14I CALIBRATED AIRSPEED, V_c (Knots)

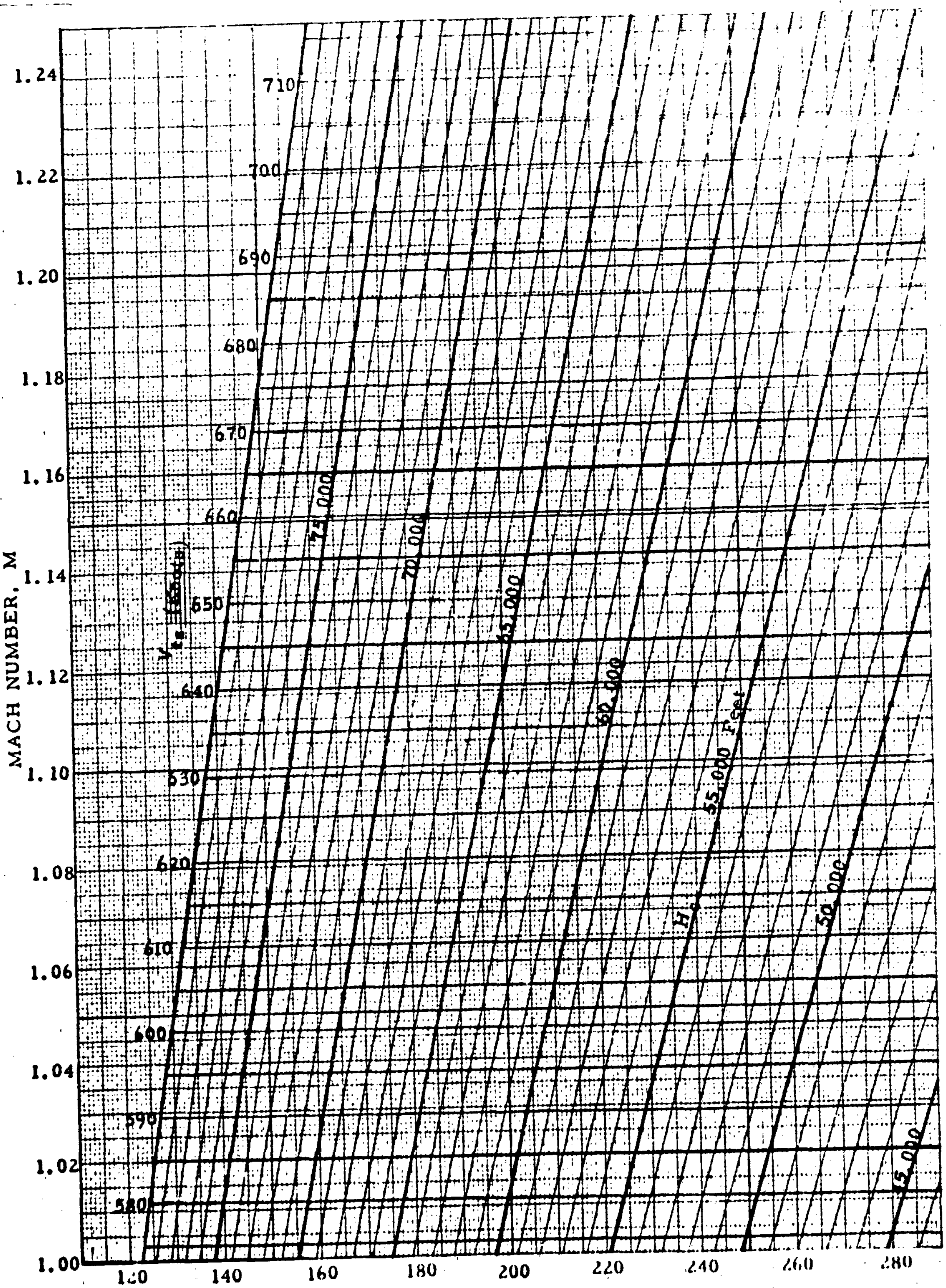


FIGURE V 14J CALIBRATED AIRSPEED, V_c (Knots)

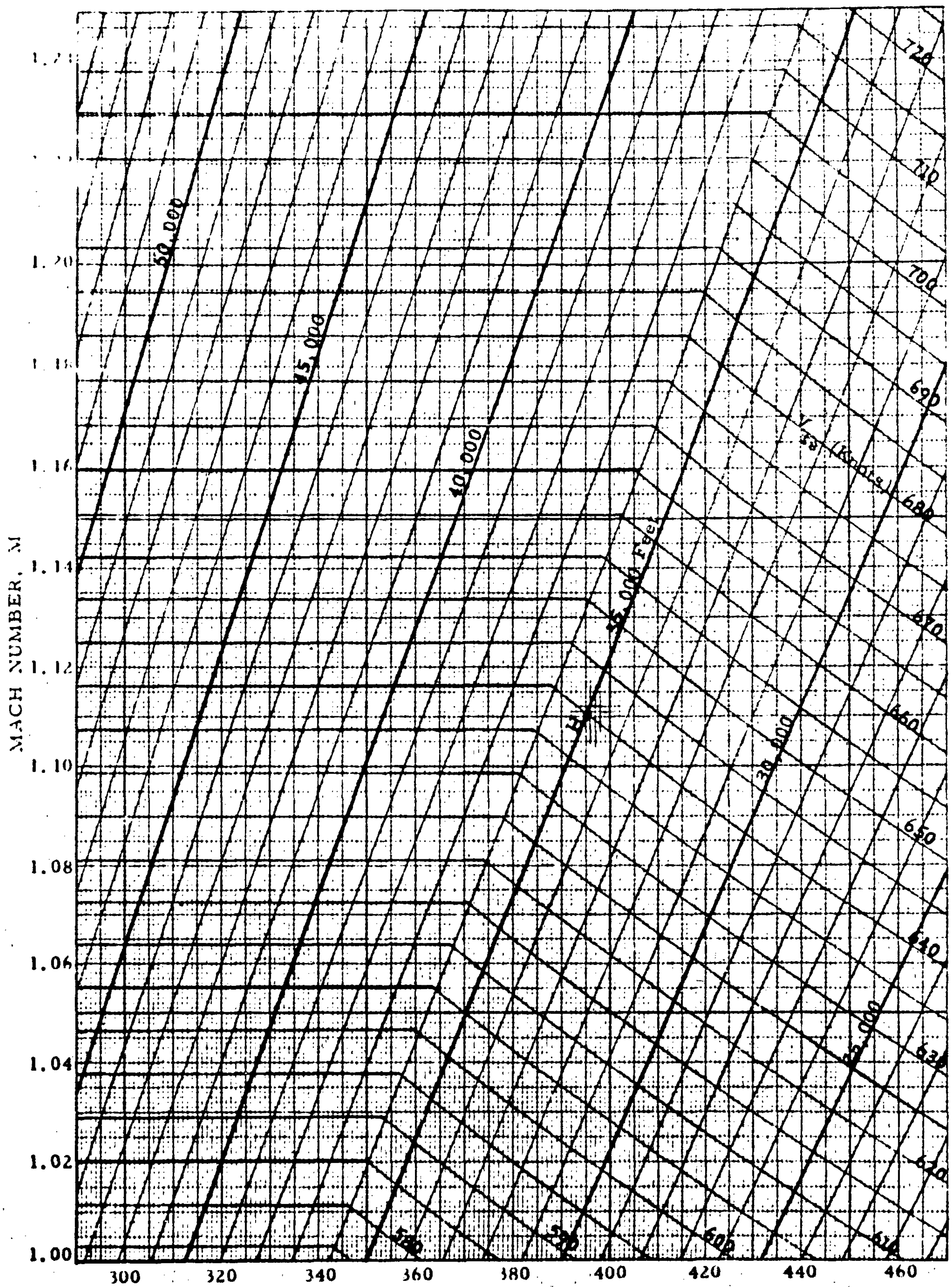


FIGURE V 14K CALIBRATED AIRSPEED, V_c (Knots)

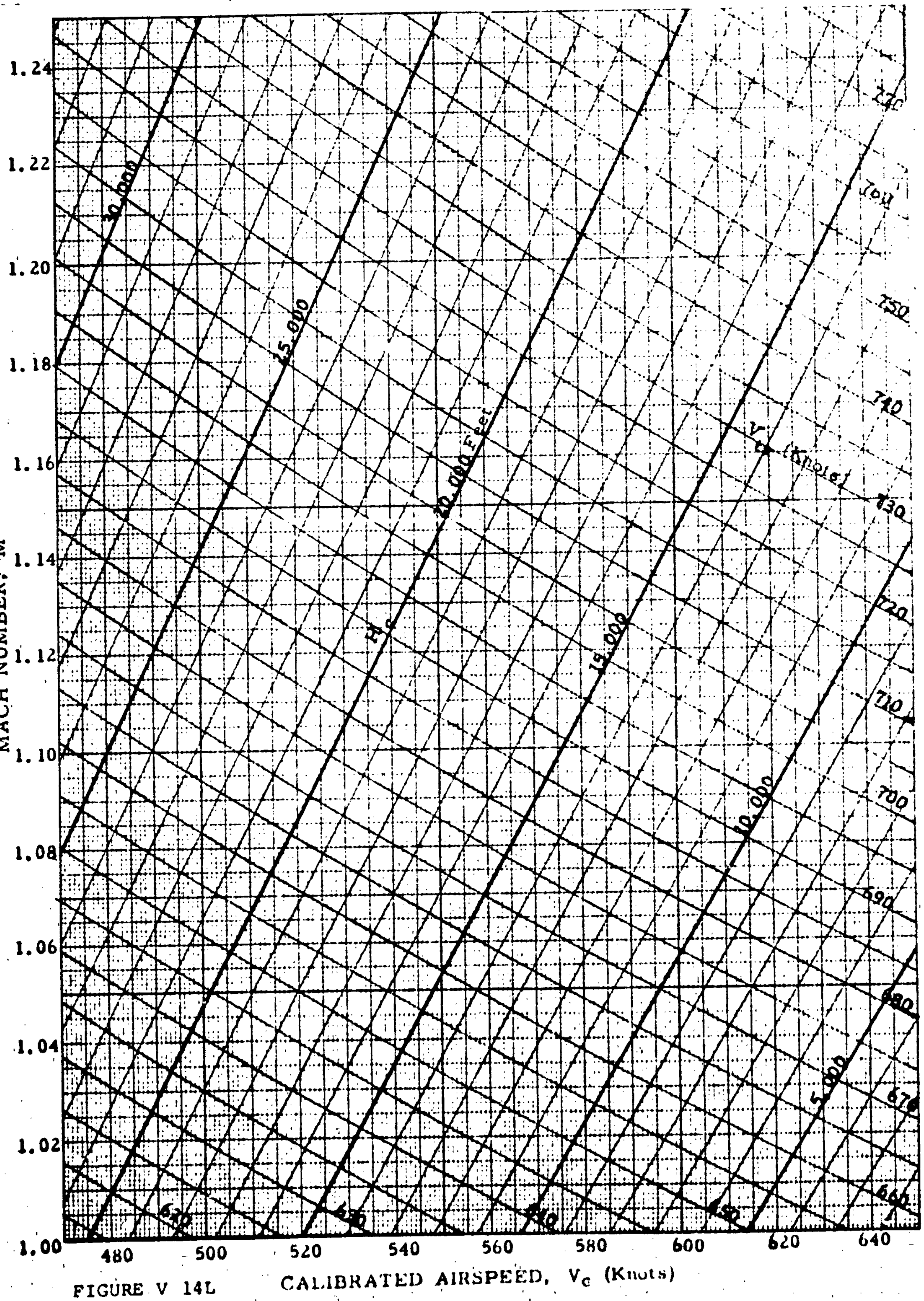


FIGURE V 14L CALIBRATED AIRSPEED, V_c (Knots)

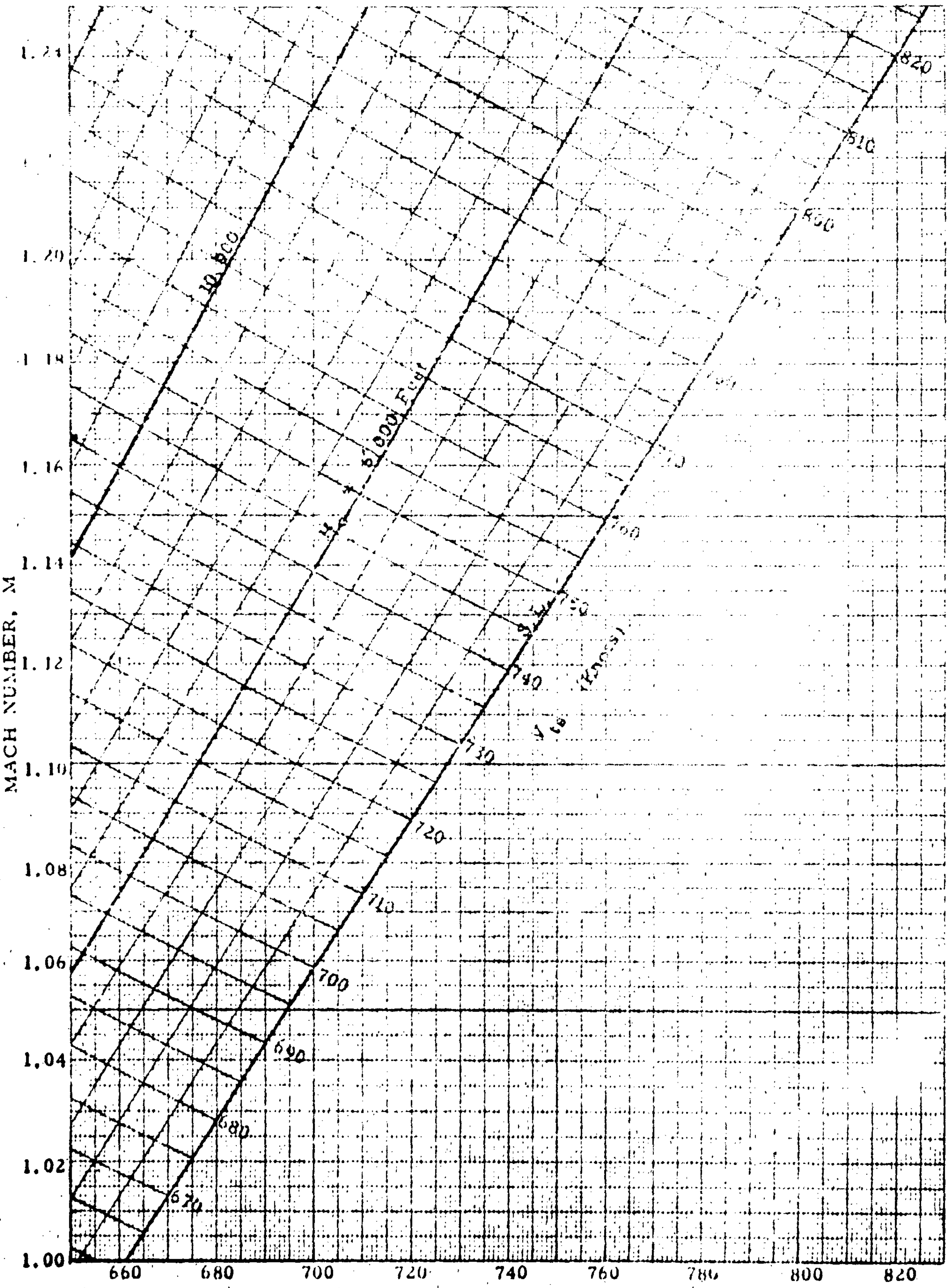


FIGURE V 14M CALIBRATED AIRSPEED, V_c (Knots)

LIST OF ABBREVIATIONS AND SYMBOLS

Item	Definition	Unit
AFFTC	Air Force Flight Test Center	--
AFTR	Air Force Technical Report	--
ALT	altitude	ft
ARPS	Aerospace Research Pilot School	--
A/S	airspeed	kt
avg	average	--
a_t	test day speed of sound	kt
C	centigrade	--
CAS	calibrated airspeed	kt
C_L	lift coefficient	--
CTR	counter	--
DIR	direction	--
EL	elevation	ft
FAT	free air temperature	deg C
ft	feet	--
FREQ	frequency	mc
FLT	flight	--
H_i	indicated altitude	ft
H_{ic}	indicated altitude corrected for instrument error	ft
ΔH_{ic}	altitude correction for instrument error	ft
ΔH	incremental height	ft
ΔH_{pc}	altitude position error correction	ft

Item	Definition	Unit
H_c	pressure altitude = $H_{ic} + \Delta H_{pc}$	ft
ΔH_t	fly-by tower height	ft
H_T	tapeline altitude	ft
Hg	mercury	--
hr	hour	--
Hz	frequency	Hertz
in.	inches	--
Ind	indicator	--
ICAO	International Civil Aviation Organization	--
IAS	indicated airspeed	kt
kt	knots	--
K_t	temperature probe recovery factor	dimensionless
M	Mach number obtained from V_c and H_c	dimensionless
mc	megacycles	--
M_{ic}	indicated Mach number corrected for instrument error, obtained from V_{ic} and H_{ic} values	dimensionless
ΔM_{pc}	Mach number position error correction	dimensionless
min	minutes	--
NACA	National Advisory Committee for Aeronautics	--
No.	number	--
P_a	ambient pressure, from H_c	in. Hg
$P_{a_{SL}}$	standard atmospheric pressure at sea level	29.92126 in. Hg

Item	Definition	Unit
$P_{a_{ic}}$	indicated atmospheric pressure, corrected for instrument error	in. Hg
PPM	Precision Pressure Monitor	--
P_t	total pressure	in. Hg
P_t'	total pressure behind shock wave	in. Hg
P_s	atmospheric pressure at H_{ic}	in. Hg
ΔP_p	position error correction for the static source	in. Hg
$\Delta P_p/q_{c_{ic}}$	position error correction, pressure coefficient	dimensionless
q	dynamic pressure = $1/2 \rho V_t^{\,2}$	in. Hg
q_c	differential pressure = $P_t - P_a$	in. Hg
$q_{c_{ic}}$	impact differential pressure corresponding to V_{ic}, $P_t - P_{a_{ic}}$	in. Hg
R/D	rate of descent	ft/min
S	wing area	ft^{2}2
sec	second (of time)	--
Ser	serial	--
S/N	serial number	--
t_i	indicated air temperature	deg C
Δt_{ic}	free air temperature indicator instrument correction	deg C
t_{ic}	indicated air temperature corrected for instrument error	deg C
t_a	ambient atmospheric temperature	deg C
T_a	ambient atmospheric temperature, $t_a + 273.16$	deg K
$T_{a_{SL}}$	standard sea level atmospheric temperature	deg K

Item	Definition	Unit
T_{ic}	Indicated air temperature cor- corrected for instrument error, $t_{ic} + 273.16$	deg K
t	time	sec
TO	takeoff	--
vac	volts alternating current	--
vdc	volts direct current	--
V_g	ground speed	kt
V_i	indicated airspeed	kt
ΔV_{ic}	airspeed indicator instrument correction	kt
V_{ic}	indicated airspeed corrected for instrument error = $V_i + \Delta V_{ic}$	kt
ΔV_{pc}	airspeed position error correction	kt
V_c	calibrated airspeed = $V_{ic} + \Delta V_{pc}$	kt
ΔV_c	airspeed compressibility correction	kt
V_t	true airspeed = $38.967M\sqrt{T_a}$, for test conditions use Ta_t	kt
V_e	equivalent airspeed = $V_c - \Delta V_c$ or $V_t\sqrt{\sigma_t}$	kt
δ_{ic}	$P_{a_{ic}}/29.92126$	dimensionless
θ_t	$Ta_t/288.16$	dimensionless
ρ	air density	slugs/ft^3
ρ_{SL}	air density at sea level	0.0023767 slugs/ft^3
σ_t	$\rho_t/\rho_{SL} = 9.6306 \frac{P_{at}}{Ta_t}$	dimensionless

Item	Definition	Unit
W_t	test gross weight	lb
Subscripts		
a	ambient	
a/c	test aircraft	
c	calibrated	
db	dry bulb	
i	indicated	
ic	instrument corrected	
L	lag	
o	remote or free stream	
s	standard day conditions	
SL	sea level	
t	test	
p	pacer	
pc	position error correction	
wb	wet bulb	